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Cooperative Landing Pads

Enabling the highway to space exploration

White Paper- 2024

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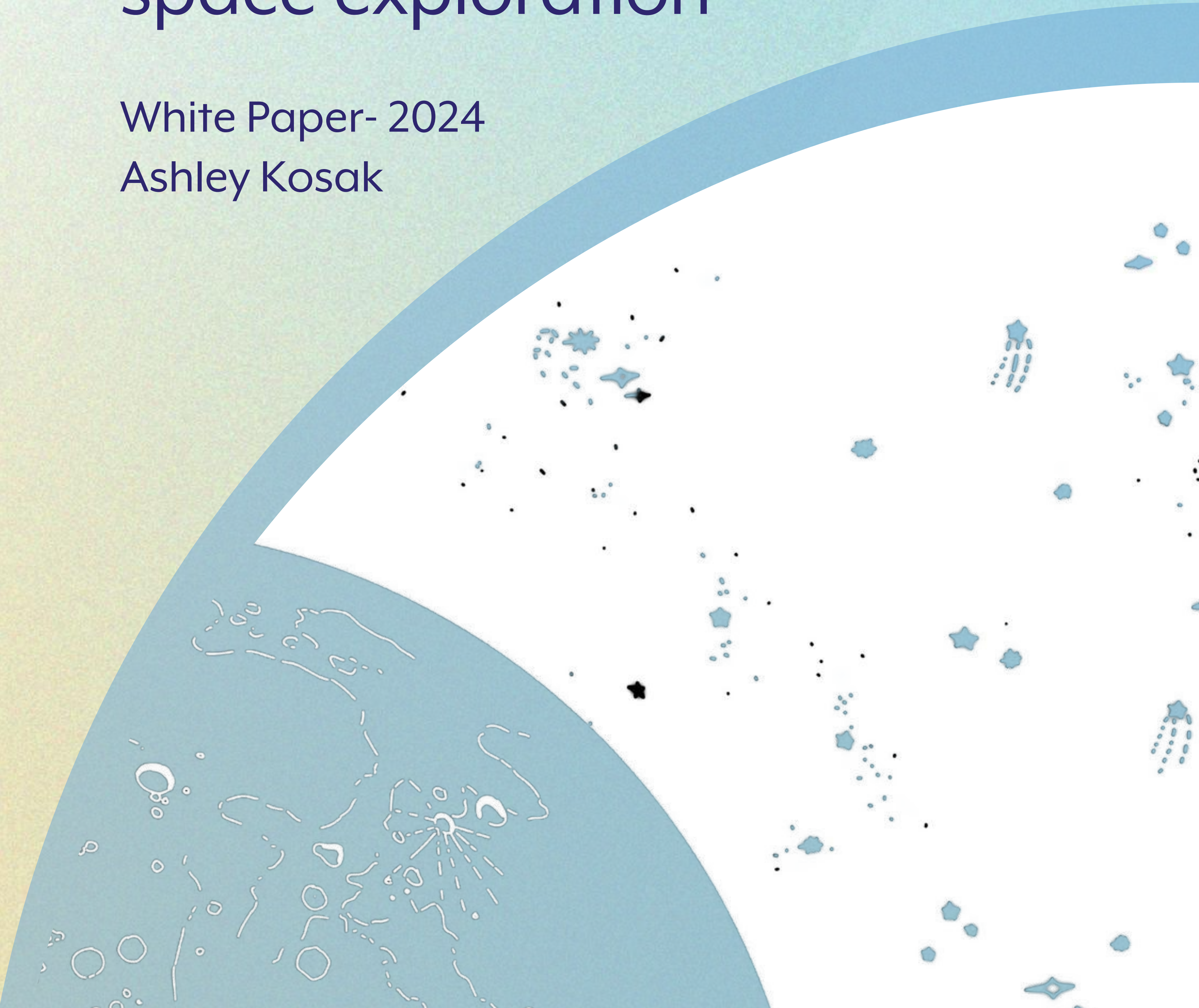

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Introduction

We are at a turning point in human history where the inhabitation of another planet is confidently on the horizon. The rapid innovation in launch vehicles and spacecraft technology has made it possible to envision a world where humans can land and live on the Moon and eventually Mars. Recent global investments in lunar landers, transportation, energy generation, and construction move the needle closer to building the infrastructure necessary for this goal, and partnerships creating orbital gateways and space stations signal a closing gap between an Earth-bound economy and a lunar economy. In order to accomplish building this infrastructure, repeated launches and landings will be necessary. In conjunction with the cargo these launch vehicles carry, they also carry a large risk of ejecta and dust plumes causing potential damage to nearby structures. A lunar landing pad will aid in mitigating regolith erosion, enhance the stability of landings, and provide a network of services to aid in key components of energy generation and communications.

Notably, it is vital to consider the risks of key pieces of infrastructure being owned by single, vertically integrated owners. It opens the risk of a singular operator to monopolizing access to these new horizons and reduces fault tolerance in a risk-intolerant environment. Through the cooperation of a multitude of international partners, we have the opportunity to build a collaborative lunar landing pad which invites space-faring dreamers in the world to contribute towards the mission of building a port to enable interplanetary civilization.

This research outlines the need for a coordinated effort to build lunar landing pad infrastructure, and it addresses logistics considerations, and design elements, performs a case study on the return on investment, and explores the various cooperative business structures.

Landing Pad Logistics

A lunar landing pad is essential for future space exploration and sustainable operations on the Moon. It provides a stable, dust-free surface for spacecraft to land, reducing the risk of damage from lunar dust and debris that can be kicked up during landing and takeoff. This dust, known as regolith, is sharp and abrasive, posing significant challenges to equipment and astronaut safety. A designated landing pad helps to protect scientific experiments and infrastructure from the effects of rocket exhaust and impact forces, ensuring the longevity of lunar bases and equipment.

Criteria for Selecting a Landing Site

The less-familiar terrain of the Moon, and the high price of accessibility, means that selecting a landing site will require careful consideration of several factors: light, darkness, communications access, and smoothness of terrain.

Peaks of eternal light are hypothetical locations on the surface of the Moon that are always lit by the Sun. It must be high in latitude and high in elevation, often found on craters. These points are advantageous due to the ability to receive solar power regardless of the time of day, and constant sunlight exposure minimizes temperature variability, simplifying the design and operation of lunar infrastructure.

Meanwhile, areas of permanent shadow are often located within craters. Again, these will be located at a high latitude, near the North or South Pole. Permanent shadows aid in the preservation of water ice, where the availability of Oxygen and Hydrogen can be utilized for conversion into water, breathable air, and rocket propellant. It's important to highlight that a landing site within this region risks difficult navigation of surroundings, cryogenic regolith, and communication interruptions.

Temperature variability can be seen in the image below which demonstrates the fluctuation of maximum solar temperatures during the summer and winter, with the south pole and Shackleton Crater located in the centre of the image. The peak alongside Shackleton and the depth of the crater both remain at a relatively consistent temperature throughout the year, as compared to the surrounding region.

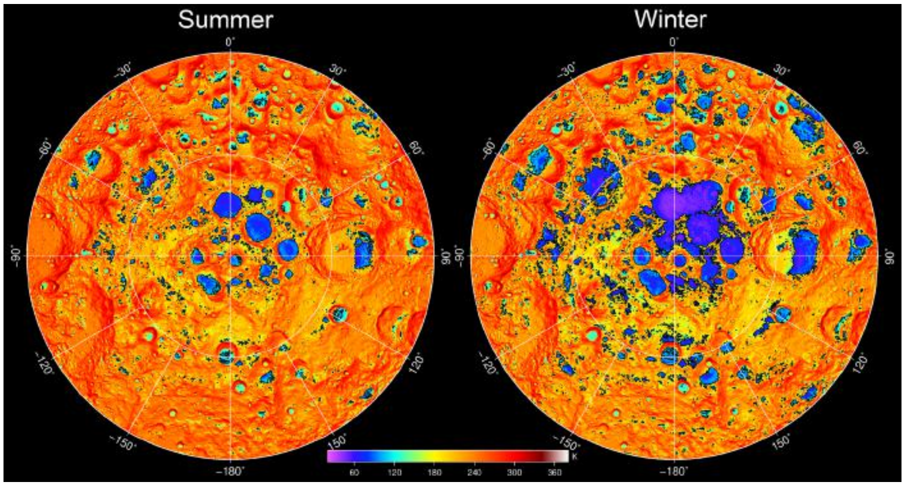

Figure 1. *Maximum summer and winter temperatures near the lunar South Pole, based on ten years of data from NASA's Lunar Reconnaissance Orbiter (4).*

A lunar lander would be best placed near the edge of a peak to a crater containing a permanent shadow, rather than within a crater. Most regions listed in Table 1 can be located within 6 degrees latitude of the Lunar South Pole, as shown in the graphic below:

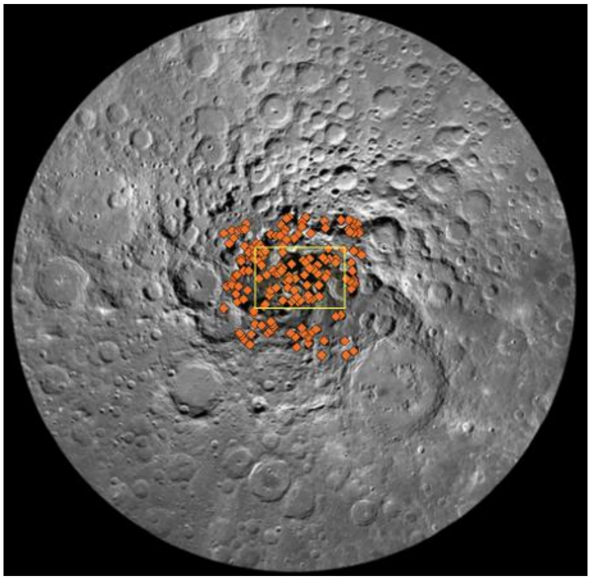

Figure 2. *Artemis Landing Site Options on the Lunar South Pole, mapped on Moon Trek (5)*

International Missions with a Common Landing Site

Historical lunar soft landing sites from the USA, Russia, and China are located at middle or low altitudes, within 45 degrees from the equator, with a notable exception of Chang’e-4 which landed on the far side of the Moon in 2018. Each lunar landing mission and lunar observation mission have aided in the characterization of terrain and collecting of samples which have aided in the meteorological analysis of terrain. Given the international efforts to understand the characteristics of the Moon, it would be ideal to utilize these findings in a shared site which can economically serve as a utility to all nations with the common goal of expanding humanity.

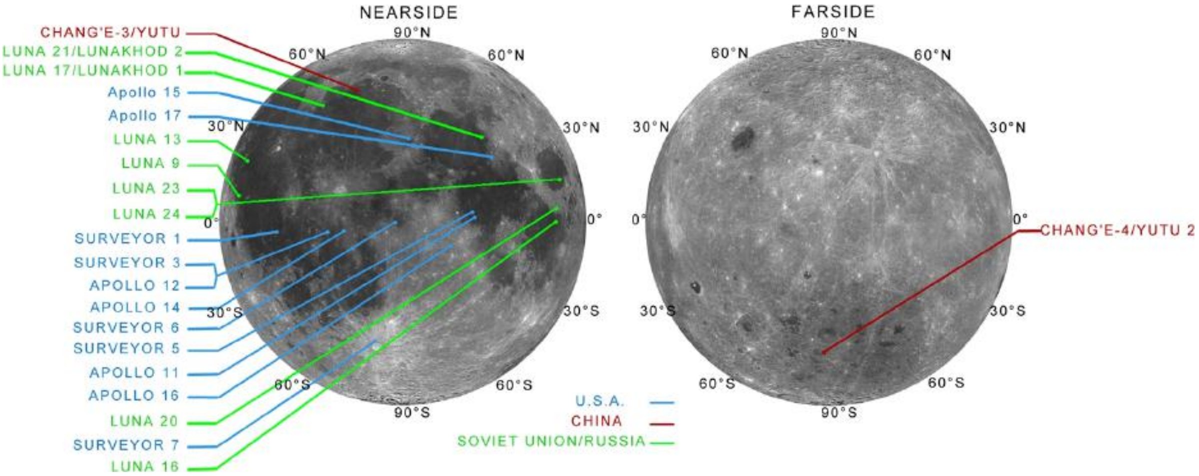

Figure 3. *A non-exhaustive list of the successful lunar soft landing sites, redrawn according to Li et al. 2019b (6)*

Looking forward towards the next generation of lunar missions, we may begin to consider the landing sites being selected by international companies and space agencies. The below table contains past and future missions announced by India, Japan, USA, and several collaborative missions such as the Artemis Accords– carrying the torch forward for lunar development and an eventual lunar gateway and base.

Table 1. Lunar Development Missions and Landing Sites

Mission	Mission Date	Organization	Landing Site
Chandrayaan-3	14 July, 2023	ISRO, India	Statio Shiv Shakti (between Manzinus C and Simpelius N craters)
Smart Lander for Investigating Moon (SLIM)	19 January, 2024	JAXA, Japan	Shioli
IM-1 Odysseus	February 15, 2024	Intuitive Machines, USA	Malapert A
IM-2	*2024*	Intuitive Machines, USA	Shackleton connecting ridge
HAKUTO-R Mission 2	*2024*	iSpace, Japan	Unknown
Artemis III	*2026*	NASA	South polar

			region (see below graphic)
Chang’e-7	*2026*	China National Space Administration	Peak near the southeast ridge of Shackleton crater
iSpace Mission 3	*2026*	iSpace, Japan	Schrodinger Basin
Artemis IV	*2028*	Blue Moon (Blue Origin, Lockheed Martin, Draper, Boeing, Astrobotic, and Honeybee Robotics) + Artemis Accords partnerships	South polar region (see below graphic)
Chang’e-8	*2028*	China National Space Administration	Leibnitz Beta, Amundsen crater, Cabeus crater and the Shackleton-de Gerlache Ridge

Missions planned for the development of a lunar base are mostly located in the South Pole region of the Moon. The Shackleton crater is near the lunar south pole, which provides eternal light and is also believed to host valuable resources such as water ice. It is also a potential landing site for IM-2, Artemis-III, Chang’e-7.

Shackleton is an example of a lunar landing site with a relatively high amount of planned lunar landings. This crater is 21 Kilometers in diameter, and the site can only be posted around the outer perimeter of the crater, not within it (7). A major concern of an increased lunar launch cadence is the impact potential of dust plumes from the propulsive landing of launch vehicles. Without an infrastructure with a well-built and maintained blast shield system, it would be highly risky to land more than one lunar lander on the site at a single time.

Additionally, the depth of Shackleton Crater is 4.1 ± 0.05 km, meaning there is a high grade of terrain to precisely land on. To make a lunar landing site of this significance a reliable resource to each of these companies, it will require several pieces of well-developed and reliable components.

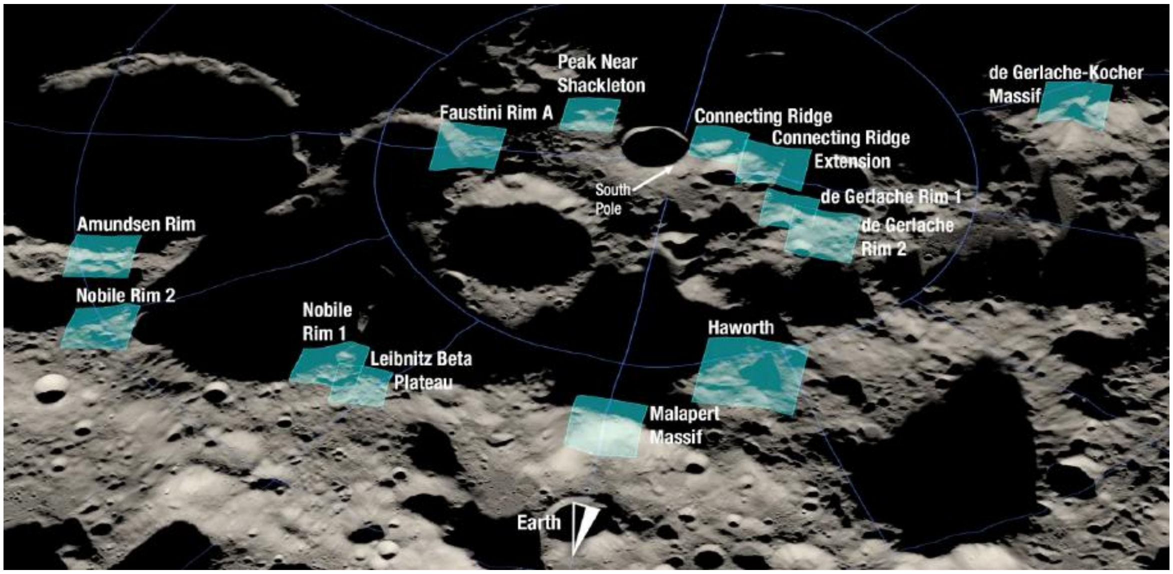

Figure 4. *Detailed list of Landing Site Options on the Lunar South Pole (8)*

Components of a Landing Pad Infrastructure

To effectively grow a lunar site alongside the growth of the lunar economy, this mission would be best served by leveraging the lessons of the vast amount of ports that exist on Earth today. Launch site complexes, seaports, and airports have all been optimized for safety and efficiency, and internationally there are standards which dictate how the companies of these ports must design their operations to adhere to strict safety standards and protocols.

Standardizing the infrastructure of a landing pad, allows companies to build to a similar engineering requirement with the assurance that the landing pad at the other end of this journey is prepared to accept their vehicle. This type of standardization is not uncommon, the ISS has standard docking ports which all vehicles must build in compliance with and test to similar standards in order to launch a space vehicle and dock. By doing so, it gives all the astronauts, engineers, and executives the assurance that this vital piece of the environment within space will be protected from the moment a mission lifts off. Building a standardized infrastructure and common qualification system means even internationally, we are all speaking the same language when it comes to a lunar landing pad.

An example of standardized launch site regulations can be found internationally, including through the United States Space Force as regulated by the Space Systems Command Manual 91-710 which dictates requirements for all launch complexes relating to build, inspection, and safety (9). Australia has a government-owned launch facility which is intended to standardize launch vehicle systems and is regulated through their Flight Safety Code (10). These codes may not be officially standard across the globe, but when looking at a few examples of launch pads internationally it becomes clear that there are common artifacts shared amongst each. With this in mind, we can begin to consider what lessons may be carried to a common launch and landing site on the Moon.

Figure 5. *Second Launch Pad of Satish Dhawan Space Centre, Indian Space Research Organisation, By ISRO*

Figure 6. *Guiana Space Centre, Europe's Spaceport, European Space Agency, By ESA_events*

Figure 7. *LC-39A (foreground) and LC-39B (background), By NASA/Jamie Peer*

A highly efficient and reliable example of a functioning port may be looked at through the lens of Japan's seaports. In the global Container Port Performance Index, Yokohama Port was ranked as one of the most efficient ports in the world. Yokohama takes just 1.1 minutes on average to load or unload a container in a standard port call. Additionally, the structures must be built to withstand unpredictably strong currents and earthquakes. These ports are governed by a legal standard, Technical Standards and Commentaries for Port and Harbour Facilities in Japan (11). This standard dictates the technical requirements, but a unique characteristic of the document is a performance hierarchy which prioritizes the design aspects necessary for a port. The hierarchy is as follows:

Serviceability < Restorability < Safety

Through this design concept, if serviceability is possible on the lunar pad itself, it can be assumed that safety and recoverability are also secured. It creates a prioritization system of design requirements, meaning that if serviceability has been included in the design of a landing pad component then restorability and safety have already been designed. Applying this hierarchical model to the prioritization of building landing pad components, we start to chart the requirements for the initial build of the pad and the technologies which will ensure it is a robust utility.

Table 2. Lunar Components associated with specific performance criteria

Performance Criteria	Description	Lunar components able to perform the task
Safety	Performance that secures the safety of human life, the structural response is to be such that the extent of damage is not fatal to the facility.	Landing Pad Base Blast Shields/Dust management Safety Zones Communication Node - Precision Landing Power Plants Traffic Control Radiation Protection Thermal management
Recoverability	Performance that enables continuous use with repairs in a range that is technically feasible and economically reasonable	Roads Geometric Inspection Volumetric Inspection Propellants management
Serviceability	Performance that enables use without inconvenience.	Extra-Vehicular Activity (EVA) and Inspection Post-processing techniques Cleaning Procedures

When considering the matrix of factors to consider when designing a lunar landing pad, the Japanese Sea Port also suggests breaking down considerations according to the permanence of action on the component.

Table 3. Actions experienced by components being designed

Action Type	Description	Example Action
Permanent Actions	*Act on a structure continuously throughout its design service life*	Self-weight, strength of regolith, lunar gravity, environmental actions such as thermal stress, etc.
Variable Actions	*Variation of magnitude from the average during the design service life*	Loads of vehicles, action due to landings/launches, Moonquake ground motion, etc.
Accidental Actions	*Difficult to predict by probabilistic statistical techniques*	Unintended collision of a lander or other objects on the pad, meteorites, lunar dust, etc.

Table 4. Performance Criteria (Verification items) for permanent and variable actions for a Lunar Landing Pad Base Structure

Performance Requirement	State	Dominating Action	Verification item
Serviceability	Permanent	Self Weight	Slip failure of inclined regolith below structure
		Thermal Stress	Slip failure of inclined regolith below the structure, Cracking of base structure
		Regolith Strength	Slip failure of inclined regolith below the structure, cracking of the base structure
	Variable	Vehicle Landing	Slip failure of inclined regolith, cracking of base structure, high erosion rate of base structure

By combining performance requirements with the dominating actions, we start to create a hierarchy of design requirements for a lunar landing pad accepting a

multitude of incoming and outgoing vehicles. Through this design concept, if serviceability is possible on the lunar pad itself, it can be assumed that safety and recoverability are also secured. In the above example, by requiring a serviceability-level performance requirement of a lunar landing pad base, a mechanism for cleaning and repairing the lunar base would be necessary.
Stepping forward into the development of an international collaborative lunar landing pad, establishing the list of performance criteria for a lunar landing pad base, blast shields, communication nodes, and other components listed as fundamental “Safety” components will aid in creating design criteria among collaborators.

Construction Providers

The mechanism for development on the Moon will require teamwork. Collaboration. An undertaking of this size will require a cislunar economy with multiple stakeholders bringing a piece to the table. To better understand the current approach for the lunar economy, a distribution of experts were consulted representing companies working on missions for the Artemis Accords, LunA-10, and founders of technology providers for the lunar economy:

Table 5. Conversations with Industry Experts based on Planned Mission Purpose

Purpose	Australia	Canada	US	Grand Total
Artemis Missions	1		3	4
LunA-10			4	4
Service Provider	1	1	2	4
Grand Total	**2**	**1**	**9**	**12**

These conversations provided insights into the growing interest and optimism for the lunar development industry. Experts from the industry as well as the experts at the Launch and Landing Pad Workshop hosted by LSIC revealed that lunar landing pads present unique challenges based on the possible scenarios of missions over the next several decades. An effective port may need to accommodate heavy rockets vs lunar landers, crewed missions vs uncrewed missions, and overlapping mission timelines. Another common theme was the necessity of a key customer base and the potential of prime ownership vs public ownership, which will be discussed in the next section, Types of Business Models.

There are a variety of potential methods for constructing a landing pad to optimize cost efficiency, energy, and material usage. The ideal methodology requires minimal transportation of goods from Earth and utilizing as many materials from the Moon as possible, primarily Regolith.

Given the variable costs and competing methods for construction, it presents another opportunity for actors to pool their resources and knowledge together so that larger economies of scale could be leveraged for a potential landing pad. In addition, there are likely to be several components to a landing pad, such as dust containment shields, fuelling services and other hard infrastructure that is necessary for lunar missions. A cooperative approach would allow actors to focus on their specific area of expertise, as opposed to needing to build all aspects of the landing, reducing the cost burden on each individual actor and thus speeding up mission times.

Table 6. A non-exhaustive list of global lunar development companies

Component	Company	Location
Construction/Roads	ICON CisLune iSpace Astroport Europe	USA USA Japan Europe + USA (joint venture)
Communication	Crescent Space (Lockheed Martin) Surrey Satellite Technology Limited Thales Alenia Space	USA UK France + Italy (Joint Venture)
Power Plants	Astrobotic Technology Northrop Grumman Honeybee Robotics Mitsubishi Heavy Industries	USA USA USA Japan
Geometric/Volumetric Inspection	Redwire Leonardo Advance Navigation	USA Italy Australia
Propellants management	Orbit Fab ispace Mitsubishi Heavy Industries	USA Japan Japan

Designing Cooperative Pads Business Models

Due to the high amount of resources which will be necessary for machines and materials to be brought to the Moon, there will be a natural scarcity that exists in the building of a lunar civilization. In the effort to quickly innovate and develop on the Moon, scarcity of access can only serve to slow down this pace.

The many design considerations of location, utilities, and infrastructure contribute to the complexity of what it means to create a useful port of entry and exit. Leveraging the strengths of those who specialize in building each of these components will enable this effort. In fact, it will be necessary to lean on their expertise for a rapid innovation of this scale. Considering these complexities, as well as the unique topography of the Moon, it can be stated that lunar landing pads are a necessary first step in the cis-lunar economy and ideal landing sites will be high in demand. Meaning, that those who have access to the capital to build such a large infrastructure will be the first ones to stake claim to these locations. Enabling a lunar landing pad with standard and shared infrastructure ensures that all space-faring nations have a shot at creating a presence of their humanity outside of Earth's atmosphere.

Types of Business Models

Privately Owned Development

In a privately owned development, a singular company will own the land and operations of the lunar landing site. Prime owners may select contractors with specialities in the components previously mentioned, however, those contractors will not retain equity in the property. Any profit made from this infrastructure will be also funnelled towards the private owners.

There are many benefits to this model. Vertical integration enables rapid iteration of designs and a detailed view of quality controls which are vital to a mission with a high risk-posture. Engineers are able to design, build, and test with internal systems that have been optimized for efficient and effective communication. In a scenario where time is of the essence, this is an incredibly powerful model.

The effectiveness of this model can be observed in the automotive industry. Original Equipment Manufacturers (OEM) control the manufacturing and technical trajectory of a product while maintaining several tiers in their supply chain which can comprise 75% of the manufacturing lifecycle, as noted in a case study from Copenhagen Economics (12). A similar model can be observed in the current aerospace industry, where companies like SpaceX, Blue Origin, Relativity, Planet Labs, and Millenium Space Systems opt to control a majority of the in-house manufacturing process.

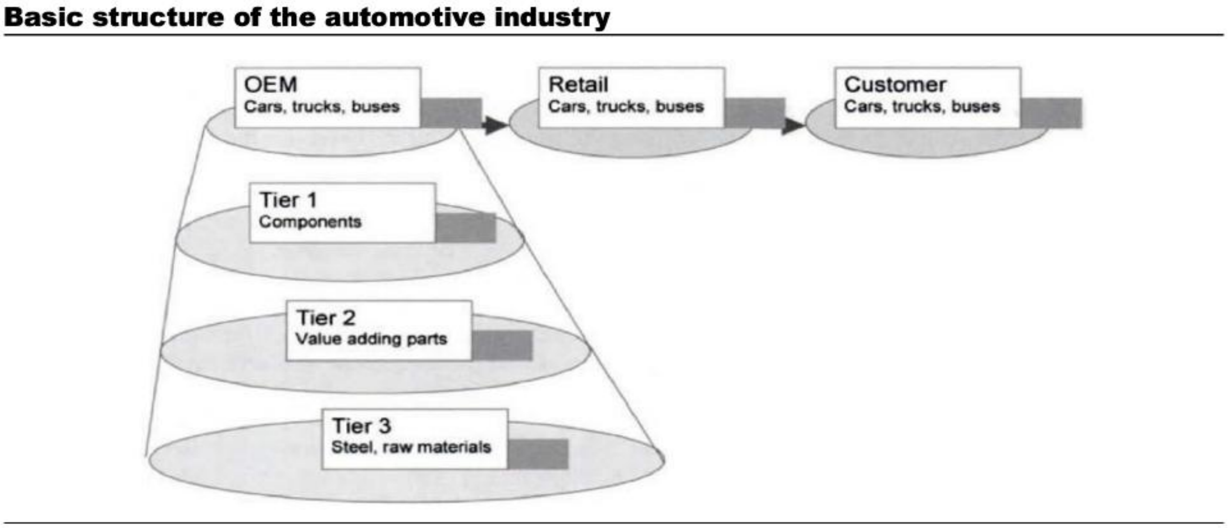

Figure 8. *Structure of tiered supply chain structure (13)*

Private owners will have the opportunity to decide on access to this lunar landing pad. Much like venture-backed startups, this may mean opening the landing pad for use for a broad array of companies and countries at the beginning of the development of the Moon, and pricing landings at a lower price point as an investment and incentive to drive economic development. Over time, as a lunar pad develops and the economy becomes further reliant on a lunar landing pad, a prime owner may decide to increase prices or adjust control to support private interest. Ultimately, this poses the risk where a lunar economy is built and dependent on a single landing pad, and quickly the owner of that key utility may decide to price out competition without a diligence process or supporting documentation providing rationale for the pricing increase. Operators that have been dependent on the utility will be in a position to have to pay the higher premium without much choice, given the significant investment placed in its section of the lunar economy.

Joint Venture

Another potential option for development would be a Joint Partnership. Joint ventures, such as the P3 Network formed by Maersk, MSC, and CMA CGM, and the United Launch Alliance (ULA) between Lockheed Martin and Boeing, offer examples of industrial applications for joint ventureships on large undertakings.

The P3 Network aimed to optimize shipping operations and reduce costs through shared resources and coordinated schedules, demonstrating how joint ventures can enhance operational efficiency and market reach. Similarly, ULA leveraged the combined expertise and financial resources of its partners to provide reliable space launch services. However, P3 Network struggled with regulatory approvals and potential conflicts due to differing management styles and objectives. Meanwhile, ULA had to navigate complex decision-making processes and profit-sharing arrangements.

For a lunar landing pad, a joint venture could pool the necessary resources and expertise from various aerospace companies, enhancing technological capabilities and reducing individual financial risks. However, there may be legal roadblocks to navigate around due to the International Traffic in Arms Regulations, which may also introduce management complexities and require careful alignment of strategic goals to ensure the venture's success.

Governance

Public-private partnerships (PPPs) can offer a robust model for developing and managing lunar landing pads, evolving into a form of governance over time. An illustrative example is the Port Authority of New York and New Jersey, which began as a joint venture between the states and private investors to manage regional transportation infrastructure. Over time, it transitioned into a comprehensive governing body that oversees a wide range of infrastructure projects, from bridges and tunnels to airports and seaports. This evolution was driven by the need for coordinated management, regulatory oversight, and sustained investment. Similarly, a PPP for lunar landing pads could start with private companies providing the initial capital and technical expertise, while governments contribute regulatory frameworks and long-term strategic planning. As the infrastructure matures, this partnership could evolve into a formal governing structure, ensuring that the landing pads are operated efficiently, safely, and equitably, much like the Port Authority today.

The necessity of governance structures for lunar landing pads is paramount to ensure equitable access and compliance with international laws. The Outer Space Treaty, signed in 1967, provides a foundational framework that emphasizes the peaceful use of outer space and prohibits national appropriation. This treaty can be leveraged to develop governance structures that ensure no single entity monopolizes lunar landing sites. For example, the treaty's principles of non-appropriation and the benefit of all humankind can guide the creation of an international regulatory body overseeing lunar landing pads. This body could enforce standards, manage conflicts, and allocate usage rights to ensure fair access for all nations and private entities. By establishing a clear governance framework based on international law, the development of lunar landing pads can foster cooperation, innovation, and sustainable growth in space exploration.

Intergovernmental Development

Intergovernmental development offers significant advantages and challenges, as evidenced by projects like the International Space Station (ISS), CERN, and the

Artemis Accords. The ISS is a prime example of how shared financial burdens and pooled expertise from NASA, Roscosmos, JAXA, ESA, and CSA can sustain a long-term human presence in space, enhancing scientific research and technological advancements. Similarly, CERN, with support from 23 member countries, underscores the benefits of collective resources in achieving groundbreaking scientific discoveries. The Artemis Accords, involving multiple space agencies, facilitate peaceful and transparent lunar exploration through international cooperation, setting a framework for future missions. These collaborations show how intergovernmental efforts can lead to shared infrastructure that enhances operational efficiency, reduces costs, and fosters innovation.

These partnerships also face notable challenges. Complex decision-making processes, divergent objectives among participating countries, and significant administrative overhead can slow progress and create conflicts. For instance, the ISS requires consensus from all partner nations, which can delay critical decisions. Similarly, CERN occasionally struggles with funding and resource allocation disparities among its member states. Applying this model to lunar landing pads could harness the benefits of shared infrastructure and pooled expertise, providing a robust and efficient solution that reduces individual financial risks. Yet, it would also necessitate careful management to navigate the inherent complexities, ensure aligned strategic goals, and maintain long-term commitment from all partners. This balanced approach could enable a sustainable and economically viable lunar presence, leveraging the strengths of intergovernmental cooperation while mitigating its challenges.

Geo-political restrictions and risks present additional challenges for intergovernmental collaborations on lunar landing pads. These restrictions can arise from shifting political landscapes, national security concerns, and differing regulatory environments, potentially leading to conflicts and delays. International sanctions or export control laws can restrict the sharing of technology and resources, impeding collaborative efforts. Overcoming these challenges may mean establishing clear agreements that outline the roles, responsibilities, and rights of each participating country. Implementing robust conflict resolution mechanisms and fostering transparency and trust among partners can also mitigate geo-political risks. Additionally, creating a governance structure that can adapt to changing political climates while maintaining a focus on the collective goals of the mission can help ensure the long-term success of the project.

Case Study

As part of the effort to better understand the financial landscape and implications of a lunar landing pad, conservative figures from The Cost of Lunar Landing Pads with a Trade Study of Construction Methods by Phillip T Metzger (14) were utilized to determine the launch rate necessary to reach a return on investment (ROI) of a lunar landing pad. Assumptions are as follows:

Table 7. Assumptions of costs for lunar landing pad case study.

Assumption	Description	Qty	Unit
Initial Investment*	Costs involved in building the launch site.	$229,000,000	$
Cost of Materials*	Cost per lb for carrying from launch site to Moon	$300,000	$/kg
Import Materials	Quantity of supplemental materials imported per year	25	kg
Operating Costs	Annual maintenance and operational expenses. (Cost of Materials x Import Materials)	$7,500,000	$
Rate of Operating Increases	Accounting for increases in costs or inflation	1.05	% increase
Launch Revenue	Fees from launch and landing site usage, maintenance, etc.	$7,500,000.00	$/Launch
Post Development Revenue	Cost of landing site usage following completed development of lunar landing site, and operational lunar economy	$10,000,000.00	$/Launch

Table 8. Return on Investment calculations created for this cast study based on assumptions to understand the potential revenue of a lunar landing pad business

Launches	Launch Revenue ($/Launch)	Operating Costs ($)	Revenue ($)	Profit ($)	ROI Point ($)
5	$7,500,000.00	($229,000,000)	$37,500,000.00	($191,500,000.00)	$229,000,000
10	$7,500,000.00	($7,500,000)	$75,000,000.00	$67,500,000.00	$236,500,000
25	$10,000,000.00	($8,682,188)	$250,000,000.00	$241,317,812.50	$261,325,938
30	$10,000,000.00	($9,116,297)	$300,000,000.00	$290,883,703.13	$270,442,234
40	$10,000,000.00	($10,050,717)	$400,000,000.00	$389,949,282.70	$290,065,063
50	$10,000,000.00	($11,080,916)	$500,000,000.00	$488,919,084.17	$311,699,232

Operating Costs *- First line includes the initial investment for infrastructure, following lines assume a yearly maintenance cost with a 1.05% increase for inflation yearly*
Revenue *- Launch revenue multiplied by Launches*
Profit *- Revenue subtracted from Operating Costs*
ROI Point *- Revenue point at which the operating costs accumulated are neutralized by the profit generated from launches*

Considering the high investment required for a lunar landing pad, a cooperative landing pad will require the backing of an institution with a high threshold for risk tolerance. In this case, such a company will need to be able to support anywhere between 25-40 launches to reach a return on investment for the lunar landing pad, assuming that prices of lunar landing pad will increase after the completion of a lunar base.

Considering the high cost of launch and landing sites, tertiary services may also be considered for this case study of lunar landing pads. If the yearly carried materials can be used for additional services, perhaps additional solar energy generation, habitats, additional fueling infrastructure, and roads can be built to add further convenience to the lunar landing site offering.

Financing a Lunar Landing Pad

An undertaking of this size will require the financing to match. An initial investment could cost $130M to $548M depending on transportation costs (14). This venture will likely need government backing, similar to how NASA's Moon to Mars mission is fostering international collaboration, including the European Space Agency, JAXA, and the Austrian Space Agency, to develop sustainable lunar infrastructure. Government support can provide the necessary funding and political stability to initiate the project, ensuring that foundational technologies and infrastructures are established.

Internationally, significant investments in lunar development have been made. Between 2012 and 2020, $40 billion was spent on the Artemis program and $20 billion was added in 2021 to account for the SLS Block 1B, Mobile Launcher 2, and Gateway programs. The total expected for the project is around $93 billion, representing the significant investments already being dedicated toward lunar development by the US Government, agnostic to the private investments dedicated towards prime contractors within NASA's space development program.

Additionally, engaging various companies to invest through their contributions of work and expertise is crucial. For example, StarLabs' joint venture partnerships with Voyager Space, Mitsubishi, and Airbus demonstrate a successful model of leveraging industry collaboration to achieve ambitious space goals. These companies can offer technical skills, innovative technologies, and financial resources, significantly reducing the burden on a single entity.

Ultimately, securing a diverse investment portfolio is essential. Companies with a strong interest in consistent lunar landings and launches, such as commercial space enterprises and international space agencies, will be critical stakeholders. The necessity of a lunar landing pad as a port structure underscores its importance as one of the initial utilities to be developed on the Moon, establishing a strong customer base ahead of the emerging lunar economy. This strategic approach not only ensures the feasibility and sustainability of the lunar landing pad but also sets the stage for a thriving lunar presence, driven by both governmental and commercial interests.

Drawing parallels: The Internet and the Moon

A completely new era of the world was created after the invention of a single piece of technology: the internet. The invention of the internet has shifted the modern world, and to navigate that terrain, Google created a highway which helped users navigate this broad network. Over the past 26 years, Google's strong innovations and algorithms allowed it to bring in $70.4 billion through Google Services revenue as of March 2024, as announced by Alphabet in their first quarter financial results (1). By all economic measures, this is a massive success story.

At their essence, journalists serve as a filter to understand and validate the truth of a story to the best of their ability and write about stories across the globe. As accessibility to the web expanded, documentation moved to the websites where news outlets were able to benefit from advertiser revenue to fund their journalism as the media landscape shifted away from printed publication. Recently, Google released an AI feature which will reduce the need to navigate to a webpage to understand a subject, trained on learning language models which ingested the millions of web pages created by these news sites. By reducing the need to navigate to these sites, news pages may see what is estimated to be a 40% drop in clicks, translating to a significant reduction in ad revenues in an already struggling industry (2). Meanwhile, the reduction in site clicks will result in increased profits for Google.

Google was able to grow its value by creating an infrastructure which became necessary for navigating the Internet. The core product, the search engine, was built on the network of companies that built websites to answer all the questions users may have. Now, with the creation of an AI to reduce navigating away from Google's platform, the highway built with thousands of exits to these sites has created an ability to sight-see without ever leaving the car.

There is a lesson to be considered when creating a highway to lunar and martian development. When a singular entity owns the sole access to necessary infrastructure, it creates an immensely useful tool which can be used to build a thriving environment for expansion. However, it leaves the means of access in the hands of a singular entity with its own interests. It lacks representation of international partners and may control the pricing access of competitors for the main port for lunar development. It creates the risk that a cislunar economy could be built through this port, and then the price can be rapidly or suddenly shifted to price out smaller aerospace players and economically benefit a singular entity. On the other hand, a company having the resources for an undertaking of this size would allow for the rapid iteration of development on the Moon at a pace we could have never imagined during the first lunar landing in July of 1969.

55 years later, in July 2024 at the Lunar Launch and Landing Facilities Workshop hosted by the Lunar Surface and Innovation Consortium, Starship was a primary example of a lunar landing vehicle when discussing the potential lunar landing pad. A key component of the SpaceX engineering system is its ability to vertically integrate, and part of its LunA-10 proposal includes Utility Starship providing backhaul between the Moon and Earth (3). In order to do so, a launch and landing pad will be necessary to mitigate the risk of ejecta during launch, and there is a strong possibility a lunar landing pad will be vertically integrated in order to do so. Again, while this would be an admirable undertaking, an international and collaborative landing pad will ensure that no matter how the tides of lunar developments shift, there will always be a port that enables access for innovations to

land on our Moon and have a chance at bringing their humanity to lands outside our orbit. It also allows for access to this landing pad to be based on purchased launch windows and does not compete with the launch schedule of the prime owner.

The Directions of Lunar Landing Pads

Missions planned between 2024 and 2028 are expected to enable the lunar launch industry to begin a cadence of launching once per year. A lunar landing pad will be a force multiplier in doing so, especially if it provides access to the international countries attempting to develop their lunar pads in parallel.

In order to build a piece of infrastructure with high structural demands, safety mitigations, power demands, and communications coordination there must be a central guiding practice dedicated to ensuring that all operators of a port will be speaking the same language no matter where their hardware comes from. This has been successfully accomplished in the past by building the International Space Station, and a similar approach may be appropriate here. However, it is important to consider the pace of innovation, which could be significantly slowed by relying purely on governmental actors to develop this type of technology.

Due to the sizable requirement of capital investment, the recommended path forward for a lunar landing pad utility would be through intergovernmental development and public-private partnerships. International governments should invest in creating a lunar landing mission with a dedicated set of providers which enable the initial lunar landing pad product. As the product becomes more efficient and standardized, policies can be put in place to make the lunar landing port the official regulatory standard for lunar landing hardware and communications. This allows for things like fuel connectors, communications relays, and other interconnecting hardware to be built with a sense of predictability for what will be connected on the other side.

In order to ensure access remains equitable and accessible, a cooperative lunar landing pad built through an intergovernmental effort will ensure infrastructure is built as a shared utility rather than purely being a profit driver. While the rapid innovation of private development may decrease the timeline of a return on investment for a lunar landing pad, it will also have the control to turn the knobs of pricing or open and close access to ports as deemed necessary.
By creating a collaborative international lunar landing pad, access to the Moon becomes a known factor rather than an unknown variable.

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Appendix A. Soft Lunar Landing Sites

Mission	Country	Landing Site
CHANG'E-3/YUTU	China	Aitken Basin
LUNA 21/LUNAKHOD 2	Russia	Le Monnier crater
LUNA 17/LUNAKHOD 1	Russia	Mare Imbrium
Apollo 15	U.S.A	Hadley-Apennine
Apollo 17	U.S.A	Taurus–Littrow
LUNA 13	Russia	Oceanus Procellarum
LUNA 9	Russia	Oceanus Procellarum
LUNA 23	Russia	Mare Crisium, fell over upon landing
LUNA 24		
SURVEYOR 1	U.S.A	Oceanus Procellarum
SURVEYOR 3	U.S.A	Oceanus Procellarum
Apollo 12		Ocean of Storms
Apollo 14	U.S.A	Fra Mauro formation
SURVEYOR 6	U.S.A	Sinus Medii
SURVEYOR 5	U.S.A	Mare Tranquillitatis
Apollo 11	U.S.A	Tranquility Base, Sea of Tranquility
Apollo 16	U.S.A	Plain of Descartes
LUNA 20	Russia	Mare Fecunditatis
SURVEYOR 7	U.S.A	Tycho crater
LUNA 16	Russia	Mare Fecunditatis
CHANG'E-4/YUTU 2	China	Von Karman crater, Far side of the Moon
Chang'e-6	China	South Pole Aitken Basin