What Are Potential Landing Sites on the Lunar South Pole for In-Situ Resource Utilization (ISRU)?

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ABSTRACT

Global interest in the Moon greatly diminished with the conclusion of the United States Apollo Missions of the 60’s and 70’s. This decreasing interest is starting to turn around, however, as NASA conducts its Artemis missions in order to promote increased interest in going back to the Moon. Interest on the Moon is back on the rise as many space agencies -- including the US, China, Japan, Canada, and the European Space Agency – are both competing and working together to create a permanent presence on the Moon. In order to accomplish this, we will not only have to choose a suitable landing site for a task of this magnitude, but also an exact purpose of what a permanent lunar base would do. From acting as a location for brand new research capabilities, such as realizing the effects of low gravity on human physiology and the utilization of new types of telescopes unusable here on Earth, to being a brand new step forward for humankind's exploration of space, a lunar base has many benefits. The goal of this paper is to showcase what exactly we can use a lunar base for and a couple of the most prominent and viable candidates for places to land on the Moon for a mission of this scale and complexity.

KEYWORDS

In-Situ Resource Utilization; Lunar Base; South Pole Aitken Basin; Lunar regolith; Lunar ice; Permanent Structure

INTRODUCTION

With ever increasing technological developments it is becoming increasingly obvious that the next step for humanity is back to the Moon permanently this time. This is actively being showcased with the ongoing set of Artemis missions being conducted by NASA (1,2). In order to accomplish this we will need to establish a permanent structure on the Moon (3,4,5). Although there are many promising locations for this, the South Pole Aitken Basin (SPA) is considered to be the most promising due to its potential use for In-Situ Resource Utilization (ISRU) (6,7,8).

ISRU is a highly active area of lunar research (9,10,11). The United States and other nations are currently considering sending both robotic and human-crewed missions to the surface of the Moon in order to assess the abundance and potential concentration of hydrogen-bearing compounds, including water, which have potential uses as fuel for rockets for supporting human activities at permanently crewed Moon bases (12,13,14,15).

There are many reasons as to why a lunar base would be beneficial. A lunar base's main utilization is as a refueling point for potential deep space missions using preexisting lunar surface ice as fuel, allowing rockets to be refueled and relaunched (12,13,14,16). Along with serving as a refueling point, it would also be able to house telescopes that are able to look further into space than ever before, allowing us to achieve higher quality images of other stars and planets (17,18,19,20). And finally, it can have potential industrial uses by refining minerals, such as iron, nickel, and quartz-from ancient meteor impacts all over the surface (13,21).

However, a lunar base has many potential cons to its use. One of the most major cons is the sheer cost of putting permanent structures on the Moon. It is also difficult because something like this has never been done before as it is too complex and expensive of a mission, but also the safety concerns that would come with it (3,4,5). With this base not only are there concerns of the safety of very sensitive equipment due to the vacuum of space and the lack of an atmosphere on the Moon to protect such equipment, but also human safety (3,4,22,23). A base like this would need a constant crew aboard, however: from intense temperatures, radiation, and varying light levels from the sun, along with other surface hazards, there are many things that make the Moon inhospitable for human life (22,23). With a catastrophic failure of support systems, death would be extremely likely due to these conditions. Because of the importance of safety for a mission like this, the selected landing site for a mission like this is paramount for the safety of both the astronauts and equipment needed. This necessity for a suitable landing site is the primary factor that many space agencies are actively deciding on for their own missions (8).

This project weighs the advantages and disadvantages of different potential landing sites for crewed missions under consideration by NASA, mostly concentrated at the lunar South Pole. Here, I review the peer-reviewed literature on proposed lunar landing sites that are under consideration by NASA and other space agencies for ISRU (8).

LUNAR BASE UTILIZATION

A permanent structure on the Moon would provide many benefits to Earth both economically and technologically (3,4,5). These benefits would not only be beneficial to just the space agencies involved in missions like this, but to everyone on Earth.

One of the major ways that a lunar base could benefit Earth economically is by harvesting lunar ice from the surface and refining it down to hydrogen and liquid oxygen (12,14,16). This is a very common combination of elements that is used as fuel for many of today's spaceships. Some notable examples of rockets that have used this combination include the Saturn V, the Space Shuttle, and NASA's current SLS launch system (1,2). This would make the rest of our solar system much more accessible for space travel because, by being able to refuel on the Moon, the cost of such spaceflights would be a fraction of the current cost (16). This is mainly because of the lack of an atmosphere and low surface gravity on the Moon, making launches use less fuel to lift the same amount of weight. Being able to manufacture and store our own fuel on the Moon would also prove to be extremely beneficial as it would allow us to utilize the Moon as more than just another planetary body in our solar system to visit, but rather as an extension of Earth's own industrial and technological capabilities (16,24).

Another major way we could utilize a lunar base is through the implementation of deep space telescopes within the base (17,18,19,20). This would allow an enhanced observation of space both within our own solar system and potentially even beyond into other star systems. With the telescopes being on the Moon, with no atmosphere to combat with, they would have a much clearer image than anything we would be able to get on Earth (17,18,19,20). This is also beneficial as there are many other types of light (such as x-rays and gamma rays) that are unable to reach the surface of Earth due to our atmosphere. The benefit for x-rays and gamma-rays is they otherwise get absorbed and blocked by our ozone layer, preventing them from reaching the surface. Another type of telescope that has been unusable on our surface due to the atmosphere is thermal infrared (IR) light. Our planet gives off too much of a thermal signature for IR to function on the surface. However, due to the absence of an atmosphere on the Moon's surface, the Moon would be perfectly capable of supporting an IR telescope. Another less common type of telescope on Earth that could prove to be very useful on the Moon is that of Ultraviolet (UV) telescopes [20]. On Earth, there are many limiting factors to the effectiveness of UV telescopes; these cons range from the atmosphere absorbing almost all UV radiation to human caused light pollution causing images to become much more distorted. Many of these issues can be immediately resolved if these telescopes were placed on the lunar surface where these issues are non-existent (20).

One major caveat that needs to be discussed about the use of telescopes on the lunar surface is the existence of lunar dust on the Moon. Although there is no atmosphere to carry it, it is still able to move due to electrostatic levitation on the lunar surface (25,26). This movement of lunar dust is able to become increasingly detrimental over time to any surface telescope as it would cover the lens, causing the telescope to become unusable (25,26). This however, can be completely negated, as if there was a permanent human presence on the Moon, it would be possible for the telescope's lenses to be routinely cleaned, giving us crystal clear images of the space beyond our own planet. The use of these telescopes would have a profound impact on our scientific capabilities. With the ability of clear deep space imagery, we could make scientific discoveries we never would have known existed. Along with telescopes, a permanent human presence on the Moon would also allow for the study of decameter radio wavelengths. These wavelengths range from 10 meters to 100 meters and have never been able to be studied before on Earth due to our atmosphere (17).

A lunar base also allows for an increased amount of study on the impacts of low gravity on the human body (22,23). This is because a mission of this scale would have to be permanently staffed and inhabited by astronauts. If given the proper equipment and ideal circumstances, these astronauts would be able to greatly improve the level of research into exactly how low gravity affects human anatomy (22). This area of study has been given some focus by NASA through the use of zero gravity on the International Space Station (ISS), however the amount of research available on the ISS is very limited. These limitations would be rectifiable with a lunar base as it would allow a more in depth analysis on how the Moon's low gravity would impact the human body (22,23).

Additionally, a lunar base can be utilized as a way of experimenting and testing certain complex ideas and procedures that would be crucial for permanent structures on other planetary bodies within our Solar System. More specifically, a planet such as Mars. The Moon is the perfect testing ground for something like this, as if things were to go wrong and a rescue were necessary, it would only take a matter of days instead of months like it would if something were to go wrong on Mars (22). The development of a lunar base would allow us to test how many mission critical components required in a mission to Mars and beyond would actually function and survive within the harsh environments of both space and planets with a lower gravitational strength than that of Earth (3,4,5,22).

INCREASING GLOBAL FOCUS ON THE MOON

The Moon has slowly become an ever increasing topic of interest for many governments and space agencies around the world (1,2,27). With many major space agencies looking outward to the Moon for resources, research, and as a stepping stone for eventually landing humans on Mars and beyond (1,2,3,4,5). With the establishment of the Artemis Accords in 2020, many global space agencies have agreed to almost full transparency and cooperation for any and all future space exploration. This includes missions and even any possible permanent bases established anywhere in the solar system (27).

NASA has become a pioneer in modern day space exploration after seeing a decline in its activity around the exploration of the moon since the Apollo missions of the 60’s and 70’s (1,2). With the ongoing Artemis missions aiming to put humanity back on the surface of the Moon, for permanent this time (1,2). The proposed 10 mission long program aims to gradually ramp up in complexity, from the next Artemis II mission planning to just do a flyby of the Moon, all the way to landing humans on the Moon and putting a permanent space station in orbit of the Moon -- the Lunar Gateway Station -- in missions III and onward (1,2,28). This is no small endeavor, with NASA not doing it just by themselves. They have outsourced many different aspects of it to other major space agencies and companies around the world.

One of the most notable national agencies collaborating with NASA for this is the Canadian Space Agency (CSA). For decades CSA has mainly focused on robotics and space infrastructure, and they will now be able to put it on full display as they are designing many of the robotic and infrastructure systems planned to be in place on the Lunar Gateway Station (28). One of the more major private companies selected to be a part of the missions is Elon Musk's SpaceX. For the missions, SpaceX has been given the role of designing and developing the Starship Human Landing System to actually land the astronauts onto the surface after they reach orbit of the Moon (1,2). This level of international involvement just for one program shows how we are able to set our differences aside and come together to better all of society.

Along with NASA, many other national space agencies have also shown their own increasing interest in the exploration of the lunar surface. The most notable and successful example of this is the China National Space Administration (CNSA). Although they are one of a few nations who are yet to agree and sign the Artemis Accords, they have made copious amounts of progress in their own exploration of the Moon. They have achieved this through their Chang'e Program which has achieved many historic milestones in its own right. Not only have they become the first space agency to successfully softly land a spacecraft on the far side of the Moon, but have also become the first agency to return surface samples from the far side of the Moon. Something that has never been done before as all other samples from the Moon have come from the near side before this. The CNSA has also become one of the first ever space agencies to have deployed Ultra Violet (UV) telescopes on the Moon's surface (20). These telescopes are able to capture images that have never before been seen and are a very large step for humanity's increasing focus on utilizing the Moon as a staging ground for new forms of telescopes. These accomplishments showcase how the U.S is expressing an increased interest in the Moon, but other countries as well. A lot of these independent organizations are also working in conjunction with one another in order to further advance this field of research, as it has become a global point of focus for the scientific community.

LANDING SITES

While we could technically set a base up anywhere on the Lunar surface, the most useful locations for both ISRU and construction of telescopes would be on either the North or South Pole (12,13,29). This is because the Poles have more potential for having surface ice deposits compared to the rest of the surface and can offer some of the clearest images of space (12,13). The poles have more suspected ice deposits due to lower levels of direct sunlight allowing ice from water-rich asteroids to stay frozen on the surface, due to much lower surface temperatures (12). The Poles also offer a much better place to set up telescopes as they experienced a longer period of darkness than anywhere else on the lunar surface. This extended amount of darkness will prove to be especially beneficial to UV telescopes as they function best when there is an absence of light (20).

The South Pole has been more predominantly focused on by many space agencies planning on going back to the Moon. This is due to the South Pole Aitken Basin (SPA) and how it is located almost directly on the South Pole (6,7,8). The SPA is a large (over 2500 km wide and 8 km deep) impact basin on the far side of the Moon (6). This basin has gradually become one of the most promising and viable landing sites for a mission back to the Moon for many different reasons (8).

The SPA is suspected to be one of the oldest impact basins in the entire solar system (6). Due to its depth, it is suspected that most of the surface is some of the deepest surface rock exposed on the surface (6,30). It is especially important due to the fact that the Southern edge of it is located almost directly over the South Pole. In this southern edge, there are many smaller craters within the SPA. These smaller craters are the primary targets of future lunar exploration (8). There are 3 main ones that are focused on more in depth by professional space agencies. These are de Gerlache crater, Shoemaker crater, and the Shackleton crater. These are not the only three though, as there are other craters in this area, however they are not as majorly focused on as these three due to their size and potential of containing deposits of ice and other sought after materials (8,12).

Out of the three major craters listed, the Shackleton Crater is by far the most talked about, due to the fact that it is located directly on the South Pole of the Moon (31). The Crater is a rough circular shape with a diameter of roughly 21 kilometers and a depth of 4.2 kilometers (31). Some of the standout features of the crater are that the inside is in a permanent shadow while the very outer rim of the crater is in direct sunlight over 90% of the lunar year (31). This is one of the major reasons as to why it is the most talked about landing site for a mission to the Moon, as it would provide an almost permanent supply of solar power on the edge while protecting sensitive equipment from direct sunlight down inside the crater (31).

Another majorly talked about crater within the SPA is the Shoemaker Crater. Located almost directly due North of Shackleton by about 20-30 kilometers. It is also roughly circular in shape and about 50 kilometers in diameter and roughly 2.5 kilometers deep (32). Like Shackleton, it is permanently shadowed within the crater with only the outer rim being exposed to near constant sunlight. Although it is seemingly just as promising as the aforementioned Shackleton Crater, one main issue with it is that it is almost half as deep as Shackleton, which would be less beneficial for any potential material research of the lunar regolith. This is important as the craters are able to bring subsurface rocks all the way up to the surface, with the deeper the crater, the deeper the material being pushed up is. This alone is invaluable to lunar research as it would provide scientists with a much deeper and complex understanding of what the Moon is made up of (6,30,32).

Another less talked about area that is suitable for a mission like this is on the lunar North Pole. The North Pole offers the same types of resources as the South Pole, however, the suitable landing sites within the Pole are more restricted. One of the only noteworthy possible landing sites is within the Pearly Crater. This crater is roughly 73 kilometers in diameter and 2-3 kilometers deep, offering similar levels of shaded areas as the craters on the South Pole. Although it is almost identical in opportunities for research of lunar resources, the craters within the South Pole are receiving a much more increased level of focus from every interested space agency. This is mainly due to the fact that terrain within the Pearly Crater has much more rugged and unsuitable terrain for a possible landing mission on the surface (29).

Why craters? There are many different reasons as to why craters have been seen as the best option for any sort of permanent structure on the Moon. One major reason is that craters offer the best possible location for ISRU to even be possible. This is due to not only rare metals being trapped within the asteroids that caused these craters but also the fact that craters offer an abundant amount of shade. This shade not only protects sensitive equipment and materials from coming in direct contact with sunlight, but also allows the formation of ice (12,13). With ice being one of the most sought after resources for ISRU, it is imperative that the location we choose has the possibility to even contain ice (12,13,14). As previously discussed the need for ice is largely based on the idea of being able to use the Moon as a place to refuel for any potential future missions that would go deeper into the solar system. With the main point of it being a place to refuel before heading to Mars (16).

However, these craters are fairly difficult to access and are much more complex than other potential landing sites. One of these potential sites is in the Oceanus Procellarum located on the Moon's equator. This area of the Moon is much easier to land in due to the fact that it is situated nearly directly on top of the equator. However; the resulting ease of mission planning is hampered by the fact that this region of the Moon has very little to no directly available resources that would benefit a mission of this kind (21,24). Due to the fact that it is on the equator, this region receives much more sunlight than either of the Poles, therefore almost completely ruling out the chances of ice deposits on the lunar surface, due to the extreme temperatures the surface can endure (12).

CONCLUSION

The Moon is no longer something that we should consider to be a destination in space, but rather an extension of our current scientific and industrial capabilities. Through recent events it has become fundamentally clear that through fierce global competition and humankind's curiosity, we will be going back to the Moon in the near future. Permanently. Given the many benefits of a permanent habitation on the Moon, it is imperative that we choose the most optimal location for a permanent structure with the South Pole Aitken Basin being one of the top contenders for that location. The lunar surface is the most optimal place for experiments that are unachievable here on Earth. From studying the effects of low gravity to brand new types of imagery devices, the Moon is vital to advancing our technological capabilities. With the resources that the SPA offers, future space exploration will be significantly more feasible due to ISRU on the lunar surface. The utilization of pre-existing ice deposits as fuel for future space missions is the inevitable goal for lunar utilization. The Moon is the next major step in humankind's continued space exploration with it serving as a testing ground for future missions to Mars and beyond.

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CONFLICT OF INTEREST

The author declares that there are no conflicts of interest related to this work.

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