MOON BASE – CREW WORK, RESEARCH, ON SITE MOBILITY AND COMMUNICATION

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1. INTRODUCTION

Several important aspects of the Moon base project remain to be taken into account in order to be consistent. In this part of the report are considered the following topics: the research conducted by the crew members as well as the crew activity, the on-site mobility, and internal and external communication. However, those topics are to some extent highly interrelated and define or even limit each other. So high attention has to be paid while defining those topics finer and working with them in order to avoid high costs or unnecessary risk of life for instance.

2. CREW WORK

2.1. CREW COMPOSITION

The composition of the crew will change depending on what phase the lunar base is in. It will take time to establish a proper working facility and the number one priority is to make sure everything is safe before doing any concrete science.

When everything is set up one can start assembling a semi-permanent crew in the long run. An optimized solution would of course be that every member is educated in every aspect of what needs to be done in and around the Moon base. This is of course only possible to a certain extent through general preparations before the mission; however it is not that easy to get a hold of personnel with sufficiently sharp competence within all advanced topics of research. It is therefore beneficial to bring several experts in different fields to make the most out of this very expensive mission. Fundamental areas of expertise that involve maintaining and evolving a functioning base will of course be prioritized since this is a huge part of what this mission is about, the colonization of mankind.

The most competent personnel will naturally be picked for the specific task without special selection due to sex and nationality. Some restrictions to this might have to be made depending on how the funding is received. If a considerable amount of the funding comes from say, nation A, it is reasonable that this nation gets to contribute in the success of the mission and also brings an astronaut of its nationality. If a team does not work out socially this should be detected in advance during the initial preparations for the mission. The aim of the Moon base is to hold up to six crew members for up to indefinite stay, it is therefore important to pick these individuals carefully with the mission needs in close mind.

First of all the expertise of a physician, a specialist of the human body is required to continuously check up and do research on the changes of the body induced by this new environment. Even though people have been living on ISS throughout the whole 21th century, scientists have only scratched the surface of the changes and adaptations the human body undergo due to microgravity. It would be interesting to see how far the body is willing to adapt, would it be possible to change our night and day cycles to adapt to new planets such as Mars in the future? Even though it is such a fundamental part of how the human being has been shaped it is an intriguing thought. Other duties would be to help fellow crew members if they get ill or hurt, as it would be a disaster if such a thing occurred in this remote location.

One of the fundamental parts of maintaining a base this isolated is to have a great deal of self-sustainability, a big part of this is establishing the obvious food/oxygen source that comes from various plants. Setting up a functional large scale greenhouse on the Moon might be problematic in many aspects and it needs to be established how plants react in this environment. A specialist in this field would therefore a great contributor to this space mission, setting up, maintaining and monitoring the greenhouse and all that it contains. To support all the science that needs to be done on the Moon two engineers with background in physics would come in hand, not only for the technical sciences but also exploring and interpreting different phenomenon on the Moon. Even though it is great if all crewmembers have some kind of background in engineering, it is crucial to have a specialist on board that has a deeper understanding of electrical engineering whose responsibility is to over-watch various important segments of the mission. This involves rovers, power supply from solar arrays and several other electrical components within the lunar base. Just as the electrical engineer, the mechanical engineer is a big contribution to the crew as there is a lot of machinery and devices that needs to be handled. Duties can also be to help setting up the Moon base and have overall responsibility of the base as a whole. These six are all selected with the intention of maintaining a working, scientific Moon base. Additional expertise such as a pilot and other various mission requirements are of course also required.

2.2. Crew schedule & Rotation

Setting up a working schedule in a harsh environment such as on the Moon brings challenges in safety due to the space environment. Even though rovers will do a lot of the work outside of the protective housing, they cannot do everything. The crew also needs to be able to travel freely for exploring and science-purposes. To avoid as much radiation as possible the work schedule is ideally set up in two main blocks naturally induced by the cycle of the Moon as it turns about the Earth in relation to the sun. For about six days a month the Moon is somewhat protected from radiations as it passes through the Earth's magnetotail. This might however come with certain drawbacks; as the Moon passes through this field it gets bombarded by charged trapped particles that might yield a strong sudden negative charge upon the surface of the Moon during this six day window as the tail fluctuates along the Moon. Both personnel and rovers exploring at this time may accumulate loads of excess charge that could cause a dangerous discharge, damaging or destroying electronics. [1] The magnitude of this phenomenon needs to be further established to conclude whether it is better or worse to be working outside during the passing of the magnetotail.

Changing crewmembers every six months is a good guideline to start working with as it has done before on ISS. Experimenting with longer stays in space is better suitable at the more nearby space station where the cost of bringing up and down personnel is substantially less. As for the structure of the daily routine not much will change to the way it currently works on ISS where a detailed day-to-day schedule is presented for the crew to maximize efficiency and keep their minds on something constructive to avoid depression and panic due to the desolate location. One positive difference in a health point of view compared to Earth-orbit environment is the increased gravity (about 1/6th of Earth´s) which hopefully will lead to a quicker adaptation of the body and with a lot less side-effects due to low gravity. The two hour exercise sessions that need to be done on a daily basis on ISS to prevent muscle and bone loss can surely be reduced by a significant factor due to the low but constant force on the body.

To maintain mental health, making time for social activities is important both among the crew members themselves and between the crew and loved ones back on Earth. Other than the more technical and obvious activities such as eating, sleeping, cleaning, maintenance and doing science, one great way to create public interest, which is crucial for increased funding in the future, is to record video logs or even livestreaming on a day to day basis. Astronaut Chris Hadfield´s recording of him singing space oddity

from ISS became an instant viral success and is a great example of the potential interest of space if done in the correct way.
Changing the crew on a mission like this is going to be costly and nothing one want to do too often, at the same time you do not really want to change the entire crew at once since you tend to lose small, important information that cannot be transferred easily in advance nor after the change. The future goal is of course not to have to change the crew at all and have a self sustainable working base on the Moon, that is however far from reality and the best alternative would be to send new crew in groups of three, yielding one launch every three months (excluding potential resupply-missions).

3. RESEARCH

If covered, the amount of research that could be conducted on the Moon would lead this report to extensively exceed the authorized number of pages. To get a grasp of it, NASA itself has singled out in 2006, 181 topics the US would consider investigating, would humanity one day set camp on the satellite [2]. This report has narrowed its field of investigation to three main sections. On the first hand will be considered research that focus globally on how to colonize other planets, ensuring human survival in hostile environment. On the second hand, the Moon itself shall be put under the microscope. Finally, a colony on the Moon would allow further investigation on space physics.

3.1. COLONIZATION ON MOON AS FURTHER STEP TO MARS

Already during a speech at NASA headquarters on January 14, 2004 then US-President George W. Bush set the objective to send a manned mission to Mars. However, his speech lacks of a certain time frame unlike John F. Kennedy and his goal to land on the Moon in the 1960s. [7] At first appearance the missions to Moon and Mars do not have much in common, especially the time to travel differs vastly. However, at second glance the intention to build a base on both planets offer more commonalities than one might think. Though the big advantage of a lunar base is the possibility of fast supply and rescue missions within three days whereas those missions would take a couple of months to Mars. A big topic which the space community could learn more about is how to operate a space station, which problems one encounter in such an environment and testing new tools, devices and modules. Thereby it is comparatively easy and cheap to gain those experiences on Moon instead of Mars, which makes them however not less valuable for a future Mars base.

A major topic is the utilization of greenhouses in order to produce vegetarian food supply for astronauts. In addition greenhouses can contribute to the conversion of carbon dioxide into oxygen and can help to recycle waste. Besides it has also soft benefits, for instance a positive influence on the mood of the crew which lives in barren areas like the Moon. Taking all these advantages and the fact that independent hydroponically green housing has already been tested in extreme climate laboratories and for more than six years at the South Pole into consideration makes this idea a very promising one. However, it has never been proven to work properly in space without any complications. [8] This is the part where the Moon base takes green housing up, does research on the grown vegetables, as for instance if there is a measurable influence of radiation or mutation, includes improvements, as for example robotic mechanism for growing and harvesting, and makes the entire system running as soon as possible to support and increase the sustainability of the lunar base.

Figure 3-1 A space green house

A major issue on both Moon and Mars is the dusty surface of them. It is mainly a problem in terms of covering solar cells, rovers and the visors of astronauts' helmets. Thereby the abrasive character of the Moon dust plays an essential role. The lack of weather and atmosphere on the Moon facilitates sharp particles which in addition get electrostatically charged by the Sun's ultraviolet high-energy rays and makes them highly adhesive to surfaces. The properties of dust on Mars, however, are more forgiving in mechanical terms because of three reasons. First of all the atmosphere of the Mars has two positive effects which lower their adhesiveness. On the one hand it helps to round off particles by sandstorms and on the other hand charged particles lose their charge to neutral molecules of the Mars atmosphere. Finally the higher gravity of Mars compared to the Moon reduces the potential of the particles to levitate higher and longer. [9] Nevertheless the dust problem is present on both planets but to a different extent, whereby the Moon fortunately owns the harsher dust than Mars. A factor that makes the results and devices which are used to cope with dust on Moon very likely applicable for future missions to Mars in combat against Martian dust. One of those devices to clear plane or slightly curved surfaces from dust can be for instance "the lunar dust buster" ([10]) which produces an electrical wave by a phase-shifted electrical field in order to lift and move charged particles on its surface. Yet this device has only be tested with simulated lunar or Martian dust, so it needs further research with both real lunar dust as well as the classic conditions on Moon in order to prove its capability as well as the possibility to operate in a long time frame of several years.

Furthermore the medical impact of lunar and Martian dust on astronauts' health is another important field of research. Already in 1972 during Apollo 17 Harrison Schmitt felt a so called "lunar dust hay fever" which was caused by inhalation of small (smaller than 10 micrometer) Moon dust pieces. However, he recovered quickly as the amount of inhaled particles was comparatively small but the awareness of the hazardousness of Moon dust was born and the topic is more actual than ever. The danger of lunar dust can be explained by its extremely fine size and abrasive behavior which mainly irritates lungs and eyes, yet it is at least not poisonous as the Martian dust perhaps will be. In addition to the mechanical irritating characteristic, there are assumptions that Mars soil could burn any organic compound radically and may contain amounts of toxic metal (arsenic and hexavalent chromium), which makes the Martian dust even more hazardous and difficult to handle than the lunar dust. A conclusion which suggests the assumption that it is wiser to prove the systems to work on Moon first and learn from the development of them before aiming for Mars. [11]

Finally a positive result in these areas by research on a lunar base could ease the tension that Martian dust causes engineers while planning a mission to Mars.

3.2. “The Moon is a harsh Witness”

A big interest in going back to the Moon and do further research is the fact that the Moon tells scientists a lot about the development of the Earth. Even though both Moon and Earth got hit by interplanetary comets and asteroids, comparing the surface of them, it can be seen at a first glance that the surface area of the Moon is determined by craters, whereas the surface area of the Earth contains only a small number of craters. This fact can be explained by the lack of an atmosphere and therefore a lack of climate respectively weather on Moon. In addition the Earth is a highly geologically active planet, i. e. erosion, plate tectonics, earthquakes, volcanoes and weather are constantly reshaping the crust which leads to a loss of information about the history of Earth. An additional factor which makes the Moon such a reliable witness is the same position as the Earth in the solar system.

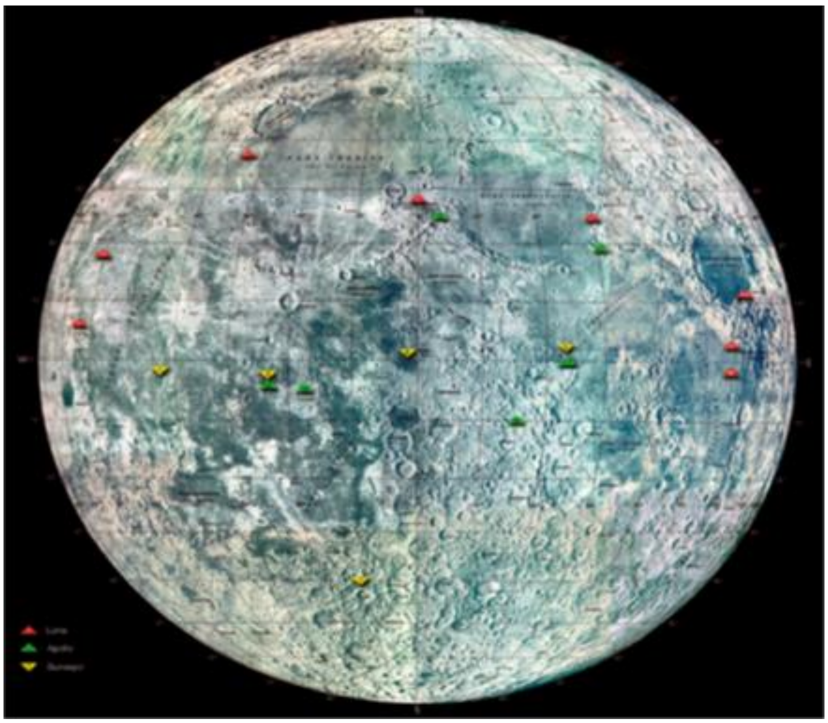

Figure 3-2 Landing sites on the moon. Luna (red), Apollo (green) and Surveyor (yellow) [4]

The samples which were collected throughout the last Apollo-missions (15, 16 and 17) could already help to find out that the solar winds composition has changed over the last 2 billion years. A discovery which cannot be explained in theory but helps to model the formation of Earth and stars, an aspect that shows the importance of Moon exploration.

A future research field on Moon could be the research on sudden mass extinctions on Earth which characterize the geological eras. The most known one is the so-called K-T extinction which is synonymous to the end of the existence of dinosaurs about 65 million years ago. There are assumptions that this was caused by a huge asteroid impact on Earth that created a tremendous climate change which led to dying plants and living beings. Further assumptions imply that this asteroid impact was no singular event, but more part of a regular asteroid shower which happens about every 26 million years. However, that theory lacks evidence and the cause of it is even vaguer. At this point the Moon and its witnessing character help scientists out again by studying Moon’s craters and determining their age.

One could think that enough samples of the Moon have already been collected, but by looking at Figure 3-2 it can be seen that the Moon missions so far landed mainly on or close to the equator. This fact leads to a certain lack of diversity in samples. Fortunately the location of the intended Moon base is the South Pole which contributes to the variety of samples when they are collected close to the base. However, especially specimens from the far side of the Moon and from its craters are of greater importance to research as those places have not been examined carefully yet or even seen by humans in person. [3], [5] In addition more specimens could contribute to a better knowledge of the composition of both the crust, the mantle and the core of the Moon. Important information which in turn could help to determine useful material located on the Moon in order to make use of it. The collected samples so far were taken only from the surface telling scientists quite well the composition of the regolith, whereas there are only theories and assumptions existing concerning the composition of the Moon's mantle and core. Those state that the core is small (responsible for only 1-2% of the mass of the Moon according to [6], 20% according to [5]), at least partly molten and consists mainly of iron with parts of nickel and sulfur, whereas the mantle, which is the layer between the core and the crust, is supposed to consist of olivine, orthopyroxene and clinopyroxene. However, these assumptions are still vague and need more proof by further research and taking of samples by drilling. A complicating factor while drilling into the mantle and core is the fact that the thickness of the regolith (from 3 to 20 meters), the crust (from 60 to 100 kilometers), the lithosphere or mantle (about 1000 kilometers) and the core (up to 500 kilometers) varies vastly so it has to be made sure that the samples are taken from the intended layer. Scientists could benefit from this improved knowledge about the composition and layout of the Moon when it comes to the theory that the Earth's Moon was once a part of the Earth itself as they both show similarities in the quantity and quality of materials so far. [5], [6]

3.3. SPACE ORIENTED

Space physics is a wide field of study and hence, the following part of the report is a selection of picked topics that present an interest in modern physics today.

The Sun is the main concern when approaching the subject of space weather near Earth. It continuously emits a flow of plasma called the solar wind that is displayed on Figure 3-1The latter is composed of high energy particles forming an ionized gas that has a temperature of around 10^5K, and a velocity of around 250-1000 km/s. Their intensity are actually at a peak when important solar eruptions take place at the surface of the sun, generating what is called a solar particle events. Plasma is a state of matter that interacts strongly with magnetic fields, so usually the Earth's magnetic field is acting like a shield to these particles. However on the Moon base, this protection would only be effective about six days a month. Predicting those solar storms would be the aim of the space weather forecast research.

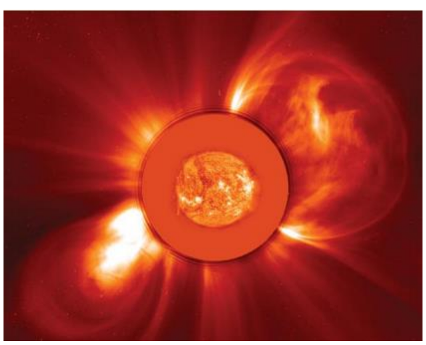

Figure 3-3 Solar magnetic field

The Sun is of active and turbulent nature, and sunspots were one of the first features observed at its surface. They are dark circular areas of roughly the size of the Earth on the surface of the Sun, and are associated with magnetic field configuration. They are often the sites of solar flares. The number of sunspots shows for the periodic solar activity of the Sun, that has a period of eleven years. We are today on the decline from a recent solar maximum as shown in Figure 3-4. The more sunspots there is on the Sun's surface, the more chance of a solar storm.

Nowadays, it is possible to predict roughly two days in advance when a solar storm is going to hit the Earth. The aim of the Sun oriented research would be to improve this forecast, implying a better monitoring of the Sun, and eventually a deeper understanding of the magnetic field of the Sun, in order to predict when solar flares or coronal mass ejections are bound to occur. One way of achieving this would be to perform low radio astronomy of the Sun. Indeed, it is impossible from Earth due to the Ionosphere, 10MHz is a maximum for these kind of observation today.

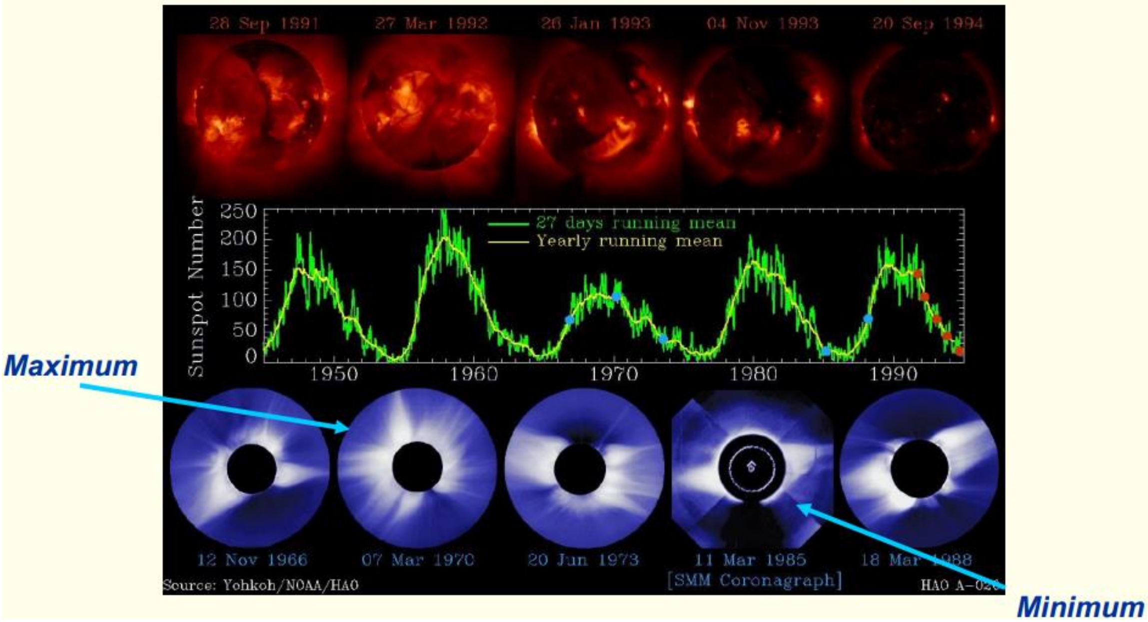

Figure 3-4 Solar cycle

3.4. WATER AND SOLAR WIND

Another important field of research is about Water and solar winds. A paper released in 2012 [17] shows for the research conducted by the Chinese researcher Yang Liu. The origin of the lunar water is unclear today, however a theory states that the hydroxyl in the lunar regolith might come from hydrogen ions supplied and implemented by the solar wind. By investigating the structure of Apollo samples via infrared spectroscopy, this scientific paper concludes that the ice polar cap “could contain atoms ultimately derived from the solar wind”.

This discovery is of main importance and deserve to be deeper investigated. Indeed if definitely proven, this theory would imply that similar mechanisms might occur on other airless planets such as Mercury of Mars. To understand how water appears on terrestrial planet without an atmosphere would allow on the one hand further understanding of the process, and may potentially yield a way of production in the distant future.

In addition the Moon is a particularly convenient place to perform low frequency astronomy. Nowadays , modern telescopes can capture radio waves from the cosmos of a frequency up to 10MHz, and allow scientist to look back in the past until 400 millions of years after the Big Bang. This 10MHz limit is due the Earth ionosphere that interferes with lower frequency waves. The dark side of the Moon would allow telescopes to capture lower frequency waves, and breakthroughs could that way be achieved in fundamental science regarding the Big Bang theory. Other fundamental fields of physics such as dark matter could benefit from a dark side of the Moon telescope. The South pole location of the base is convenient to give access to this dark side.

4. On site mobility

4.1. Automatic mobility systems

In order to satisfy the tasks required for conducting all the planned research, remotely controlled robots with the capability of travel over large distances must be taken into account, considering the limited time available for manned exploration, the research site numbers and the restricted resources available. Due to their mass and the volume occupied on the vehicle, large and medium rovers should be disregarded for the lunar mission, preferring to carry up micro-bots and reconfigure the large 3D printer to scientific purpose.

Even though the size of rovers affects the coverable distance, the spread locations of the scientifically interesting places would require a large amount of time if only terrestrial transfer were taken into account. An optimal strategy must be defined:

- micro-bots, limited to the in situ research, will perform the far exploration;
- larger rovers with greater movement capability will be allocated to the base surroundings exploration and to the site that would require deeper and more accurate analysis.

Micro rovers can be considered a feasible solution due to the possibility to be carried as piggy-back payload on the launchers and to use their capabilities of autonomous movement, and extracting, collecting and analysing the lunar material for the ground sampling experiments.

The scientific investigation of the lunar craters, involving potential risk for significant slippage and danger of the rover being immobilized by terrain hazards, possibly a mission ending scenario, requires a robust navigation system that allows to reach the study-site.

In order to do that the system must be able to:

- estimate the terra-mechanical properties in the surroundings from stereo panoramic imagery and generate high fidelity map;
- discretize objects on the path based on their dimensions, geometry and physical properties;
- assign them to the categories definitely traversable, definitely not traversable, and uncertain grounded on the quality of the calculations;
- determine the optimal path through an algorithm
- analyse the choice through a sophisticated kinematic and dynamic forward simulation;
- estimate the location and the slippage of the rover and compensate for it. [11]

Located on the arm of the rover, the Rock abrasion tool (RAL) can create an hole 45 mm large and 5 mm deep by the means of two counter-rotating grinding wheels rotating at high speed and driven by rotating grinding teeth driven by three electrical motors. Once a fresh surface is exposed, scientists can examine the abraded area in detail using the rover's other science instruments.

Thanks to low weight, small size, and minimal power consumption, the Alpha Particle X-Ray Spectrometer (APXS) represents the most suitable device to detect the composition of rocks, revealing the abundance of chemical elements in rocks and soils. The working principle is grounded on the interaction between the alpha particles and X-rays with atoms in the surface material, which is experienced through electrons extraction and X-ray emission. This radiation constitutes the source of analysis.

In order not to be limited by the small capability of carrying payload, larger rovers cover a fundamental role for the more complex experiments that require bulky tools. Despite their need, it could be inconvenient to devote launchers to them unless they specifically required it, but more interesting to reconfigure the 3D printer considering also that their purpose has come to an end once the base is built, i.e it could be possible to substitute the head with some drilling tip that could lead to the possibility to penetrate the ground deeper with the respect to microbots, to analyse thoroughly something that was only discover by the micro-bots. [12], [13]

4.2. MANNED OPERATION

Although rovers can cover all the functions to conduct research, it is interesting to perform extra-vehicular activity. The lunar environment is particularly harsh and extreme, so attention must be paid in particular to manned rovers and spacesuits.

The Lunar electric rover (LER) enables a mobile form of exploration that can provide the astronauts' main mode of transportation, and – unlike the unpressurized Apollo lunar rover – also allow them to work on long excursions without the restrictions imposed by spacesuits.

The vehicle is constituted by two separable elements: a mobility chassis and a small, pressurized cabin module that can be delivered to the lunar surface pre-integrated or as separate elements.

Astronauts can drive the mobility chassis without the pressurized cabin, by travelling in rotating turrets while wearing spacesuits.

The rover shows high levels of maneuverability thanks to pivoting wheels that enable "crab style" sideways movement to help the rover maneuver over difficult terrain and a tilt-able cockpit that gives the drivers the best possible view of the terrain ahead.

The presence of two or more LERs on the lunar surface would extend that potential range to more than 150 miles in any direction, greatly increasing the scientific opportunities during lunar missions.

With a heavily shielded cabin, the Lunar Electric Rover can sustain and protect exploring crew members for up to 72 hours against solar particle events, acute suit malfunctions and other medical emergencies.

The LER system's suitport concept allows astronauts to go out for a moonwalk. The suitport will allow the crew to enter and exit their spacesuits without bringing the suit inside, keeping the internal space mostly free of dust and reducing wear-and-tear on the suits. It also minimizes the loss of air inside the cabin when it is depressurized for moonwalks, extending sortie durations by helping the LER to make the most of its resources.

The modular design allows various tools – winches, cable reels, backhoes, cranes and bulldozer blades – to be attached for special missions. [14]

Designed by NASA, developed by Oceaneering Inc. and actually under testing, the Constellation Space System (CSS) represents the next step in the spacesuit evolution. Allowing operations in smaller ambient and ensuring higher degree of resistance to space environment, it constitutes a unique instrument for lunar missions, even more so when the Orion Crew Capsule and the Space Launch System have been chosen. The Constellation Spacesuit System is available in two layouts capable of withstanding the rigors of microgravity EVAs ("Configuration One") and the rigors of lunar surface EVAs during the monthly available 6-days for lunar sortie ("Configuration Two").

Configuration one, based on the ACES Pressure Suit, used by NASA astronauts on Space Shuttle flights, the CSS-1 features a closed-loop environmental system, high mobility capability (thanks to new bearings in the shoulder, elbows, wrists, hip, and knees) and full-pressure helmet with a swivel faceplate, incorporating a sunshade. Unlike EMU the structure consists of "only" five different layers and a minimal umbilical life-support system, due to the predominant emergency nature of the Orion EVAs, being capable of 120 hours support in case of depressurization.

Completely new spacesuits, incorporating the arms, legs, gloves, boot assemblies, and helmet from the "Configuration One" suit, the CSS-2 shows a "soft-suit" design concept, allowing astronauts to bend over and grasp objects when fully suited and pressurized, uses a rear-entry hatch design, eliminating the need for the dual-plane closure, and a new joint design, permitting to operate at a higher pressure (8 psi) and to eliminate the danger of undergoing decompression sickness. An umbilical secondary life-support system provides 150 hours support in case of malfunctioning or failure of the primary one, limiting the human activity to the base surrounding.

Cleaning of lunar dust adhered to astronaut spacesuits is of critical importance for long-term lunar exploration,
The Electrostatic Flicker (EFDR) consists of an insulating fabric electrostatically charged by a two-phase rectangular wave, forming a barrier on the surface and flicking the particles outwards. During tests in a lunar dust simulator, the cleaning rate was observed to be lower than 30% due to the impossibility of removing the trapped dust and to the absence of a proper transportation system.
The Electrostatic Cleaner (ECDR) embodies the EFDR and enhances the removal ability by a couple of holed electrodes that, charged at high voltage, transport the captured dust and transfer it to the collecting bag. The observed cleaning rate resulted to be less than 60%, as the dust problem has not been solved.
Based on the fact that lunar dust is magnetic, the Magnetic Cleaner (MCDR) work principle consists of a stationary multi-pole magnetic roller, attracting the particles, a rotating sleeve, caring of the transport by means of magnetic and frictional forces, and a magnetic plate, separating the dust from the sleeve and placing it in the collection bag. Simplicity, no power consumption and an observed separation rate of 100% make the MCDR the first candidate to fulfil the function but it requires the presence of a capturing system that could be found in a fan.

5. COMMUNICATION

5.1. EARTH-MOON COMMUNICATION

Communication with Earth is vital for the whole mission and must be a redundant system. It needs high data rates to send scientific data, communication and if possible supply the astronauts with internet to minimize the feeling of being disconnected from Earth.
The primary communication system will be based on a laser. The laser has a very narrow illuminated field which makes it power efficient. The beam is not stopped by clouds since the laser uses infrared light. The challenge is to point the laser accurate enough but this has already been tested with success during NASA's LADEE mission to the Moon.
There are several advantages with laser compared to radio waves. The laser communication becomes smaller and lighter since the wavelength is around 10,000 times shorter and there is no need for long antennas suitable for long radio waves and no parabolas for receiving signals. More information can be sent in the signals since shorter waves can handle more information per time unit. This technology is believed to be able to send up to 622 Mbit/s. [16]

5.2. MOON-MOON COMMUNICATION

Communication is vital for all activities on the Moon. In the vicinity of the base a simple antenna could be used to send and transmit radio signals. The coverage is limited since the receiver needs to be within the line of sight from the transmitter. By having the antenna on a hill or mast the coverage can be calculated by $d = \sqrt{h(2R - h)}$ where R is the Moon radius and h is the altitude above the surface. A mast of 10 m could transmit 5.9 km and a mast of 30 m could transmit 10.2 km if the landscape is flat.

When longer expeditions will be done with the help of manned and unmanned vehicles communication by the means of high masts will not be sufficient. Satellites have the advantage of high altitude and long line of sight but at the same time expensive. To minimize the cost the number of satellites needs to be minimized. By having one satellite in polar orbit the whole Moon will be covered in two weeks. Near the poles the coverage will be higher since the satellite passes there every lap. The communication will not be possible the whole time since the orbital period at 100 km is two hours. For that reason it might be needed to have more satellites in order to increase coverage. This is a trade of. How important is uninterrupted communication? This is a side of the program that is not crucial in the beginning of the base´s life but will be more important with time when the astronauts and unmanned vehicles make longer and longer journeys.

5.3. NAVIGATION

Navigation on the lunar surface is vital for all drones, manned operations as for spacecraft in the vicinity. The system needs to be accurate, redundant and easy to use. It would be very costly to set up a system equivalent to the GPS and it might be possible to achieve a far simpler system.

While going around on the ground a star tracker can tell where south is and by communicating with the satellite which comes by at least every two hours the vehicle can calibrate its position since the satellite's orbit is known. This system will not have the same accuracy as a GPS but will still provide all vehicles with sufficient navigation to know where they are and how to get back to the base.

To be able to travel larger distances faster, flying will be a requirement. This would need another system for navigation since one or a few satellites will not be able to continuously update the vehicle with navigational support. Another way of doing it with a precision that should be sufficient for most purposes would be a combination inertial navigation, radar, star tracker and a crater tracker.

Let's say that a rocket propelled vehicle is going to take a sample from a remote area. During lift-off phase the navigation will be handled by inertial navigation that uses accelerometers and gyros to calculate the velocity vector. The altitude is all the time updated with the radar. When sufficient altitude is achieved a camera similar to a star tracker will start looking at the craters of the Lunar surface. Since the whole surface is known the crates form patterns that should be possible to use in the same way stars are used in star trackers. This will be used to calibrate the inertial navigation during flight.

Possible landing site will be spotted by a camera and the flight computer will choose where to land. After landing the vehicle can wait for the communication satellite to come by and calibrate the position and by help of the star tracker the direction of the base can be known for the journey home.

6. CONCLUSION

Taking the preceding work into consideration, it is obvious that having a lunar base would be beneficial in many aspects, especially because of the advantages of different fields of science such as gaining knowledge in running a space station, observing influences of low-gravity on the human body, exploring space physics under unique conditions, and last but not least proving that such a project is both possible and feasible. Research is the final purpose of this lunar base. It is what motivates its existence, it is what justifies it to the eyes of the rest of the World. To pick what may be investigated on such an important site is a delicate subject. This could be related to the ISS situation, indeed the limit here is the crew composition, organization, up & down mass and free time. Research also determines transportation and mobility in a way, as it underlines which parts of the Moon are of interest and have to be accessed. It is also clear that the environment of the Moon leads to several difficulties. The harsh conditions can already be estimated by the huge efforts the participating countries have to face in terms of planning, running and technology. In the end, the Moon base would be worth the international effort put into it as it would both be a huge breakthrough for mankind, research and another step to a further possible colonization: Mars.

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Appendix

In the context of planetary exploration, the mobility systems can be divided in different classes, although due to the absence of proper atmosphere and any means adapt to diving, these should be limited to: rovers, hoppers, subsurface-bots and jet-bots.

I. Rovers

Rovers are terrestrial robot design to move on the planet surface and to face the contact with the ground and the friction to propel themselves, relying on different systems: wheels, tracks, legs or other exotic locomotion principles (e.g.shape-change, slithering).

Nevertheless rovers are mainly disguised basing on the mass, affecting directly the carrying capability and so on the purpose. Then robots lighter than 5 kg (micro rovers) would be typically involved scientific instruments deployment in the immediate surroundings of the lander (< 10 m) while mini and larger rovers, lighter and heavier than 100 kg, can operate in complete autonomy covering from few hundreds meters to several kilometers respectively.

II. Extravehicular Mobility Unit

Due to its longtime service and its current use for EVA, the EMU represents the starting point to understand how it is possible to operate in an environment where microgravity, vacuum conditions, extreme temperature ranges, radiation and micrometeoroids lay down the law. Unlike the common thought, spacesuits are not customized: rings made it adaptable to the already limited size of the astronauts' body and constitute the interface between each part. A complex scheme of interconnected sub-systems enables supply of breathable oxygen and elimination of carbon dioxide, stable internal pressure and sufficient movement ability, temperature regulation, ultraviolet and particle protection and communication ability where sound is not transmitted.

II.i Primary Life Support Subsystem

The PLSS is worn like a backpack and regulate suit pressure at 4,3 psi through a fan,remove carbon dioxide, odors, and contaminants from the gas supplied by the Liquid Cooling and Ventilation Garment and provide breathable oxygen, cool and recirculate oxygen through the pressure garment, and water through the LCVG, display and/or communicate astronaut and suit health parameters, contains two-way voice communication radio and a battery for electrical power.

II.ii Liquid Cooling and Ventilation Garment

LCVG is a form-fitting underwear whose main function consist in absorbing body heat through a complex system of narrow tubes and removing the sweat by crush-resistant ventilation-ducts, ejecting moist air from the extremities, keeping the wearer dry and ensuring recirculation. Sweat would be then recycled in the water-cooling system.

The small size of tubing diameter, few millimeters, and the use of plastic material, such as PVC and silicone, permits a higher degree of flexibility, but at a cost of an increased number of parallel pipes to absorb the same amount of "volume" heat, and higher pressure needed to push liquid through the tubing.

II.iii Hard Upper Torso Assembly

HUT is the central fiberglass component forms a rigid enclosure about the upper body of the astronaut, providing pressure containment, ensuring oxygen flow and connection for water drain tubes. Its structure is design to incorporate attachment points for the arms, helmet, chest-mounted Display and Controls Module, and PLSS. The HUT also includes an In-Suit Drink Bag, a plastic water-filled pouch with a tube extending into the helmet, to allow the astronaut to stay hydrate.

II.iv Displays and Control Module

The DCM is a chest-mounted unit that allows to operate the PLSS and maneuver the Simplified Aid For EVA Rescue. Gauges, valves, control sliders and knobs and switches regulates suit pressure, oxygen supply, cooling and radio volume. The main suit and astronaut health parameter are processed, displayed and communicated to the ground permitting both to the wearer and to EVA conductor to monitor them. In the end, flight capabilities are ensured by 24 small nitrogen-jet thrusters that can autonomously stabilized the attitude or manually operated thanks to an additional joystick fixable on the DCM.

II.v Helmet

Besides covering a space walker's head, Helmet's main function consists in directing the oxygen from the PLSS and the HUP to the front through a vent pad and maintaining it at the right pressure around the head. An Extravehicular Visor Assembly filters out the sun's harmful rays through a thin layer of gold and protects from extreme temperatures and small hitting objects. A TV camera and lights can be attached to the helmet.

II.vi Gloves

Unlike the rest of the suit, gloves are the unique customized part in order to promise safety and confidence in the grasp without applying an unnecessary force, resulting in hand fatigue, to allow as far as possible the sense of touch, extremely important in handholds, switches, tools handling, and to minimize mobility restrictions, while satisfying pressurization and temperature. The latter, particularly critical, is ensured by fingertips heaters.

II.vii Maximum Absorption Garment

The MAG is an adult-sized diapers in super-absorbent material that collects liquid wastes thanks to sodium polyacrylate powder incorporated in the lower layers and keep dry the skin by perspirable ones, allowing astronauts to face long-duration operation and enable peace in mind.

Looking at the EMU in its entirety, the structure fulfils all this functions with 14 different layers: the first free are devoted to the PLSS, the fourth tie the body in order to recreate the correct pressure for correct blood recirculation and holds in the breathable oxygen, the fifth shapes while the sixth is tear-resistant, the next seven layers insulate the body from the extremely harsh conditions of the space environment by Mylar and the last layer is a three fabrics layer that makes the spacesuit water, bullet and fire-resistant respectively.