OPERATIONS
BLISS - Base Lunar Installation for Scientific Studies

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***Abstract*—In order to maximize the success of a mission such as BLISS, the operations around the lunar base must be anticipated. Within the framework of this project, several subgroups form the blue team and each one tries to provide a complementary work to outline what the first permanently inhabited lunar base could look like, as well as the events which take place there. This report aims at making a state of the art of the technologies already present to realize such a mission but also of what is planned to be developed during the next years, the most promising technologies. Several points are addressed here: communication, how to carry out the extravehicular activities, the dangers to which the astronauts are exposed (radiation, lunar dust, vacuum...) and the mitigation methods which will enable them to carry out the operations successfully. Also, the rover support dedicated to astronauts during activities is discussed. Finally, considerations to be taken into account in the schedule of the users of the base are evoked, as well as a proposal of organization of group on site. Many of the concepts discussed are at the concept stage and most refer to NASA's Artemis program (which is the most advanced for a human return to the Moon today), but give hope that their application will be realized in the future.**

***Index Terms*—Human Spaceflight, Lunar Base, Moon, Operations, EVAs, Spacesuits, Schedule, Communication, Radiation, Rovers, Lunar Dust**

I. Introduction

HUMANITY is going back on the Moon, and this time it is to stay. It has been more than fifty years since the last man walked on the Moon, during Apollo 17 [1]. This had been achieved within the Space Race [2] to show the power and determination of the US nation, but now the framework is different. Different countries agree to go back on the Moon to make new science, and to prepare the future of space exploration (including heading to Mars [3]). Therefore, the preparation is different (because the aim is to insure a permanent manned presence on the Moon), and involves thus more means and coordination. As of now, such a project is probably science-fiction that is described in novels such as Artemis by Andy Weir [4], but it might not remain as it for a long time...

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A. Description of the mission

Taking a small leap into the future, we assume that we are now year 2037. The Artemis missions conducted by NASA in cooperation with other space agencies such as ESA have been successful : for the first time since the 1970s, we walked on the Moon. Furthermore, some people are already on their way to Mars, and the Moon is seen as the perfect place to set up an exploration and research base on the Lunar surface, in order to prepare for, among others, the upcoming missions to Mars.

The station has to be made in analogy with the Amundsen-Scott station on Antarctica, with a size large enough to hose up to 50 people. Furthermore, it has to be operational from the year 2040, so in a three-year span.

B. Assumptions

To set a framework for the overall project and limitations to the discussion, several assumptions are done :

- The Lunar Gateway (Lunar Orbital Station) in place
- Launchers such as Starship with the Superheavy are operational since several years
- A small temporarily crewed human habitat on the Lunar South Pole exists.
- Some extrapolation of current technologies should be done, but it must be realistic and it can be challenged.
- The scope of the project has to be limited and largely conceptual.

C. Division of tasks

The Blue Team, that was in charge of the previously described mission, has been divided in several sub-groups, namely Overall Coordination that worked on the management, cost and research issues, Station Design that studied the architecture of the base and all the aspects that this entails, Logistics, Human Aspects and finally Operations.

All of the five groups worked on their own assignments, and gathered weekly to discuss the general strategy of the mission as well as considerations that would concern everyone. During these group meetings has been, among others, discussed the mission's name that is BLISS, standing for Base Lunar Installation for Science Studies.

The main areas of concern for our group have been Communication, on the one hand between Earth and the Gateway and also between the Gateway and BLISS, and on the other hand during EVAs. The latter has been also discussed at length, and several aspects such as protocols, spacesuits, rovers, dust and radiation mitigation have been raised. Moreover, a monthly and daily schedule has been established so that everyone on the base has a clear view on what to do on a daily and monthly basis. Last but not least, an off-nominal scenario has been thought, in case of something goes out of what has been planned. This ”what-if” question is: What if something goes wrong in the communications during an EVA ?

D. Layout of the paper

In this paper, we will discuss several points following this order :

- Communication
- How to perform Extra Vehicular Activities (EVAs)
- Schedule considerations
- An Off-Nominal Scenario : Communication issue during an EVA

II. Communication

Since the location will be on the pole, the lunar base will not be at full time in line of sight of the Earth communications systems, the considered option is to use the lunar orbital station Gateway as a relay between the two ground stations (on Earth and on the Moon). Also, communication on the lunar ground will also be needed during EVAs. In this section is thus separately discussed these two types of communications.

A. Between Earth and the Gateway

1) Direct moon-to-earth communication: As opposed to the Apollo missions which landed on the near side of the moon a permenant research base located on the lunar south pole will encounter difficulties maintaining a constant line-of-sight with the earth and therefore will have a hard time communicating directly. While investigating the possibility of direct moon-to-earth communication it was found that there could potentially be established a constant line of sight on the south pole, namely on the Malapert and Leibnitz massifs [5], but with assuming the Lunar Gateway is operational and available as a relay satellite, the benefits of putting the station close to or on these massifs were not considered great enough to warrant changing the location from the Shackleton crater. However, as the Lunar Gateway alone is not able to provide full coverage, further on that below, the possibility of having direct moon-to-earth communication at the 001 site close to the Shackleton crater was also investigated. It was found that the average gap, when the 001 site is not in line of sight with the earth, would be about 83 hours, with a maximum gap 248 hours and an average number of gaps per year of 41 [5]. With this amount of blackout time the benefits of having direct moon to earth communication to compliment the Lunar Gateway where not considered great enough to warrant the extra work and equipment and the idea was scrapped.

2) Between the Earth and the Gateway: The Lunar Gateways communication with the Earth will most likely go through the Near Earth Network (NEN) which NASA intends to expand with Lunar Exploration Ground Sites (LEGS) to provide enhanced communication capabilities for future lunar missions [6]. The bands that will be used is X-band and Ka-band.

B. Between The Gateway and the lunar base

1) Purpose: As specified before, the Near Rectilinear Halo Orbit (NRHO) has been chosen for communication reasons with astronauts and lunar systems as rovers, orbiters, rovers surface systems. Indeed the gateway spends most of its time above the south pole (Apolune occuring around 70 000 km south) and thus is quite often in direct line of sight with the station location. The lunar gateway consists of two main parts for communications: the PPE (Power and Propulsion element) and the HALO (Habitation and Logistics Outpost) [7]. The first one provides power, propulsion and communication and the second one is the habitation module of the gateway and includes the Halo Lunar Communication System (HCLS). These systems are sufficiently advanced to allow real-time remote control of devices on ground. Moreover, the frequencies of the two systems are different and it explains why multiple users can be taken care of from the same location.

2) Coverage: Without any help of relay antenna on the lunar ground, using the Gateway as a relay might be an efficient solution. Hence, it is important to have an estimate of the coverage that it provides, and most, to anticipate the eventual blackouts.

Within the scope of this study, this blackout has been estimated, through basic assumptions:

- only the Moon attractive force is considered, it is thus a 2-body problem
- the Gateway's NRHO orbit is approximated by an elliptic orbit, with the same perigee and apogee. That is to say h_p = 3 000 km, h_a = 70 000 km, the respective altitudes from the lunar surface
- the the contact is reached since the Gateway is at least 15° above the horizon

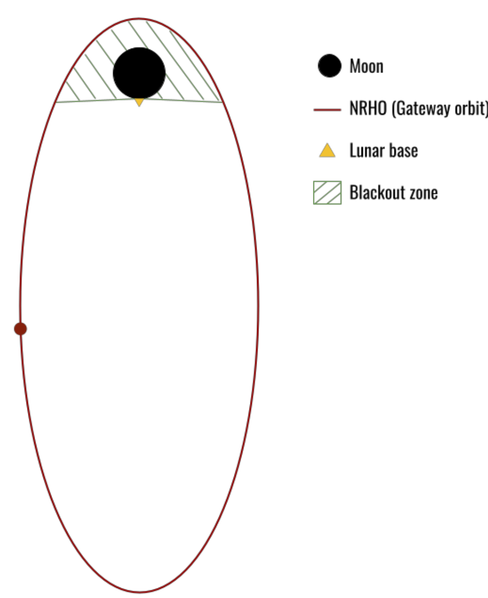

Fig. 1: Blackout zone for communication with the Gateway

Using the second Kepler's law [8], the time where the Gateway is out of reach is 5 hours each 8 days (one orbit revolution). This time seems acceptable from a safety point

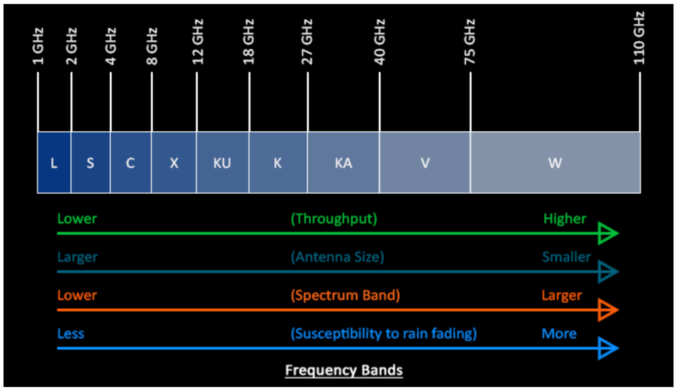

Fig. 2: Comparison of frequency bands properties *(from https://www.everythingrf.com/)*

of view, but it needs to be taken into account during critical operations.

3) Bands: For communication, 3 frequency bands will be used: the Ka-Band, the X-band and the S-band.

For the Apollo missions, mostly S-Band was used [9] thanks to a high technological readiness level at that time and a great efficiency in terms of telemetry, tracking and command, thanks to the Deep Space Network and the Manned Space Flight Network [10] [11] [12].

For the future lunar base, different choices are made, based on the choices of NASA for communicating with the Gateway, more precisely with the Power and Propulsion Element which will carry the communication facilities [13] : Ka-Band (26.5–40 GHz), X-band (8-12 GHz), S-band (2-4 GHz). See Fig 2.

One band chosen for communication between the Moon and the gateway is the Ka-band. Its use gives several advantages by providing high throughput beams, high bandwidth communication and high power for transmission. In comparison with Ku-band, the amount of data the Ka-band over a same bandwidth is much higher. It is necessary for real-time control that require high data flow rates and high power (1 Mbits/sec up and 10 Mbits/sec down). Furthermore, as the frequency associated is high, the system size is relatively small, easy to carry, to install and maintain.

Then, the X-band, presents lower data rate capacities but is more resilient. It is considered to be used for telemetry, command, ranging, and communications between either the Gateway and the lunar base, or between the Gateway and ground stations on Earth.

The other band concerned is the S-band to sustain data transmission from 24 kbits/sec to 100 kbits/sec. Even if such a system is larger, it is more convenient for slower transmission rates and it is more resilient.

C. During EVAs

1) Requirements: Good and reliable communication systems are required during EVAs since the astronauts will be on the Lunar surface on their own, facing high amounts of stress and fatigue. Two types of communication have to be established. On the one hand, the astronauts performing the EVAs have to talk to each other in order to perform the mission. One the other hand, they also have to communicate with the Lunar base who will be able to help them on the tasks they have been assigned.

The first parameter to take into account is the range of communication that would be necessary. The astronauts have to be reachable at any time, no matter where they are on the surface. This is obviously a matter of distance to the base, but also of topography. A second parameter is the wavelength, since it determines the size of the antennas needed to receive the signal. On the astronauts, the antennas have to fit on the spacesuits and be lightweight. Finally, some subsidiary aspects have to be considered in conjunction with the other groups, as for instance logistic or financial issues.

2) Choice of communication system: The Apollo missions used radio waves, and namely Very High Frequencies (VHF) that range from 250 to 300 megahertz (MHz) [14]. This has to be put in perspective with communication technologies such as Wi-Fi and 4G/5G networks that have been developed ever since.

For EVAs on the future Artemis missions, NASA plans to use a communication system based on both Ultra High Frequency waves (UHF) for the Astronaut's Voice and and Data links, and Wi-Fi for peripheral devices [15], as Figure 3 shows.

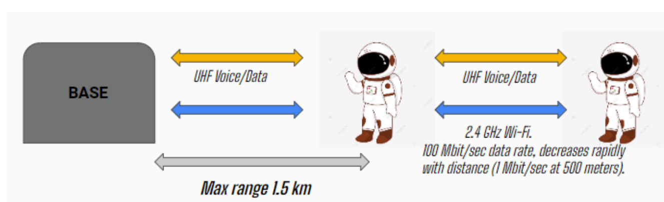

Fig. 3: Communication architecture for EVAs performed less than 1.5 km away from the base

With UHF waves inside a frequency range from 300 MHz to 3 GHz, the resulting wavelengths are quite short, from 1 m to 1 dm. This allows to have small antennas, between 2.5 and 25 cm long, that can easily fit on a spacesuit. Nevertheless, this kind of radio waves propagate mainly by line of sight and ground reflection, and they can be blocked by hills or any kind of land form. Furthermore, their intended maximum range is 1.5 kilometers. For Wi-Fi, the data rate is satisfactory (100 Mbit/second), but it decreases rapidly with distance. For instance, it becomes only 1 Mbit/second if the devices are 500 meters away from the base, which is clearly not enough for the exchange of heavy information. Thus, only EVAs realized near enough the lunar base and on a sufficiently open ground could be realized using this

UHF/Wi-Fi communication system.

This range of 1.5 km seems too restrictive and doesn't fit with the intended goals of the EVAs, namely on the one hand exploration of the Lunar surface, and on the other hand the gathering of resources such as regolith or water. A good way to tackle this issue would be the use of 4G/5G communication systems. The Finnish telecommunication company Nokia has recently reached an agreement with NASA to work on the establishment on a 4G network on the Moon by the end of this decade [16]. This would allow much more advanced communications between rovers and the lander, including High Definition images and videos or remote control of the rover. This could be done thanks to some antennas, measuring between 3 and 5 meters high, on the lunar base. Nokia has estimated that communication within a 5 kilometers range might be feasible, which fits with the depth of the crater (around 4 kilometers).

To conclude, the two kinds of communication systems, namely UHF/Wi-Fi and 4G, seem to be complementary, depending on the kind of EVA has to be performed. The lunar 4G network is yet to be established, but trusted to be operational by 2030.

III. How to perfom EVAs

EVAs and their benefits must be one of the reasons why we send people on the lunar surface: they allow to speed up research on the lunar ground, first in terms of velocity (the record of a crossed distance in a day for a rover on another body than Earth is 245,76m, hold by Perseverance since the 4th of February 2022 [17]), but not only. The human adaptability in front of a unknown context is also an undeniable advantage. Nevertheless EVAs represents also critical moments within the lunar journey : astronauts must evolves in a harsh environment, with a ”reduced version” of the base's life support systems in their suits, and accomplish tasks without failure [18].

A. Protocols

According to NASA Artemis program, EVAs (Extra Vehicular activities) will be precisely scheduled (as it is already being done in the ISS), from ”Pre EVA” phases to ”Post EVA” phases. [19]

Since the lunar ground is a rough environment, protocols must leave nothing to chance. Spacesuits must remain leakproof, mitigation against radiation must be applied, thermal aspects must be controlled... These points have been mastered by spatial agencies through the time, but the new lunar framework imposes new constraints.

Among them, the lunar dust mitigation, the base longevity and the repetition through the time (because the lunar base project is to make human lunar activities viable) need to be handled.

So, a current version of the Artemis mission protocol can serve as a base for EVAs around the lunar base.

TABLE I: Pre-Eva protocol

Pre-EVA:	
1	xEVA (Exploration System, in short : the spacesuits and its components) preparation : general checkout and consumable charges (O2, water, power).
2	Airlock Preparation (in the case where we use a airlock) : general checkout, put all the EVA's tools and needed materials/components.
3	Suit initialization (using base power)
4	Suit donning
5	Suit Checkout (primary and backup systems, final fitcheck)
6	Purge (remove N2 from suit), prebreathe

Pre-EVA:
The Pre-EVA phase, without any considerable breakthrough in terms of safety, shall begin at least one day before the EVA (as it is currently done in the ISS). The aim is basically to prepare for the EVA, as the human body (e.g. the pre-breathe phase) as the needed tools and suits to perform the EVA. The mains steps are summed up in the table I.

TABLE II: EVA Protocol

EVA		
1	Airlock depress	
2	Egress : bring the crew and EVA equipment out of the cabin	
3	Base exterior checkout, vehicles checkout	
4	Prior to ingress:	
	a	Clean up: stow tools, samples, carriers...
	b	Dust mitigation : limit the amount of dust transferred into the cabin, clean hatch, tools, bags, suits... using a brush.
5	Ingress :	
	a	Transfer EVA materials
	b	Connect xEVA umbilicals
	c	Close the hatch
	d	Begin repress

EVA:
During the EVA, the schedule might be different each time because of the operations needed, but the beginning and the end might remain the same, so that we can establish a typical protocol for that. The main aspects are the egress and ingress protocols around the airlock, and the mitigation methods. The mains steps are summed up in the table II.

Post-EVA :
From ingress, the risks are lower than in the previous phase but the aim is then to make sure that everything will be ready for the next EVA. Therefore, astronauts will have to remove the dust from tools and spacesuit, inspect the different instruments, perform maintenance as needed...The mains steps are summed up in the table III.

TABLE III: Post EVA protocol

Post-EVA	
1	Repress airlock
2	Remove particles in the atmosphere using the ECLSS [20]
3	Doff suits
4	Clean suits and inspection
5	Recharge consumables
6	Download xEVA suit data
7	Maintenance (to be defined by suit needs)
8	Swap spares as needed

One noteworthy point is that EVAs will be conducted by pairs of astronauts for safety reasons, and inside the base their must be a person responsible for the EVA (who will be able to guide them through protocols such as depressurization).

B. Lunar Dust

1) Dust characteristics: Lunar dust make part of the specific features of operating on the Moon. Apollo missions did not suffer to much of it because of the short duration of these missions. But for a permanent operation, it has to be taken into account and mitigation methods must be implemented.

In terms of composition, lunar dust is mostly composed of silison, ferrous, calcium and aluminium oxyde [21]. Because of this glassy composition, it shows a high abrasive behavior, that can damage spacecraft or even human bodies. It can also be very volatile. It's not magnetic because of a poor percentage of ferrous. However, because of the high radiation on the Moon (since there is no magnetosphere that can protect from it), this dust is electrostatically charged. This is mostly due to solar wind that hits the surface.

As a result of this high surface energy compared to the large surface to volume ratio of particles in 1/6g, the electrostatic force tends to dominate the body force. This point implies that mitigation will not be feasible with normal brushes that one can be used to on Earth.

2) Dust hazards: This "new" element in the manned space missions rises thus dangers for both spacecrafts and humans.

On equipment such as optics for observation or measurements, the dust might get stuck and obstruct the vision. Also, it can scratch gears and can cause severe impacts on their uses. Furthermore, this dust can deteriorate mechanisms and jeopardize their motions, whether it is bearings, bushings, gears, ball-screws, seals, lubricants, rotating surfaces, or fasteners.

In terms of human aspects, research is still in progress, trying to determine how bad is lunar dust for the organism. The Apollo astronauts were already affected by its presence in the lunar module when they were not wearing their suits. According to their sayings, they smelt like "burnt gunpowder" in the module, and some were affected by sneezing, nasal congestion and lung irritation, and it took several days to clear up...[22] Harrison Schmitt (Apollo 17 astronaut) described these symptoms as the "Lunar hay fever".

For now, this subject is not mastered yet, but there are ways to mitigate the known effects.

3) Mitigation methods: Currently, several research paths are considered in terms of mitigation [23]:

- Surface coatings that repel the dust
- Removal of the dust
- Altering the local lunar surface environment
- Charged brushes
- Systems that are designed to be tolerant of the dust
- Redundant systems that use a combination of these approaches

None of these are able to be applied to all component. The choice of the best one will be the chosen depending on the component and its needed operation.

Until now, the highest removal percentage reached by these methods is about 95% (within Earth conditions, this might be different on the Moon), it was performed by Kawamoto [24]], using both electrostatics forces (more efficient on fine particles) and body vibrations.

Electrons beams show also encouraging results [25].

C. Radiation exposure

One of the biggest threat in the lunar environment is the radiation exposure. Contrary to Earth, the Moon lacks of a strong magnetic field that can protect its surface from space threats. Space radiation is dangerous because it is made up of high-energy particles and radiation that can penetrate the human body and cause damage to cells, tissues, and organs. It can be classify in three different categories: Solar Winds, Solar Cosmic Rays and Galactic Cosmic Rays.

Solar winds are streams of charged particles, composed mainly by protons and electrons, that are ejected from the sun's corona at high speeds. Solar cosmic rays, on the other hand, are high-energy particles that originate from solar flares and are more threatening than Solar winds. Galactic cosmic rays, as the name suggests, come from sources outside the solar system and are composed of high-energy particles such as protons and heavy ions, and are the most dangerous radiations that astronauts may get through.

The moon lacks a protective magnetic field, which means that it is exposed to high levels of radiation from these sources. As stated before, exposure to these kind of radiation can lead to different health risks, including an increased risk of cancer, genetic mutations, and other radiation-induced illnesses. All of them can be fatal for astronauts. This is why measures had to be taken to assure optimal protection during EVA on the moon.

D. Spacesuits

To perform EVA has previously described in the lunar arid environment, an adequate spacesuit is required. The one using during the Artemis mission called Exploration Extravehicular Mobility Unit (xEMU) seems to be a suitable choice.

Fig. 4: Spacesuit xEMU designed by NASA for the Artemis Mission

Two different companies have made a deal with NASA to design spacecraft for the Artemis Mission, Axiom Space and Collins Aerospace. The spacesuit that will be selected will be the one designed from Axiom Space from this mission. Using a company to provide this service helps to reduce the cost of designing and building new spacesuits for Moon missions.

Fig. 5: AxEMU designed by Axiom for the Artemis Mission

In this picture, the color of the spacesuit is not the final one. In this kind of EVA, spacesuit will require to be white to reflect heat from the sun. One of the main requirements of the spacesuit is to protect Astronauts from extreme temperatures, and this must be done by using a white outer layer[26].

It has been designed to fit spacewalks on a planetary surface or in micro-gravity, thanks to interchangeable parts. This adaptable design allows for the same core system to be used across different missions, including those to the International Space Station, the Gateway in lunar orbit, the Moon, or even Mars.[27] In total, 16 xEMU spacesuits will be on the station, four per airlocks.

1) Overall characteristics: This spacesuit is optimized for lunar walking, with supports EVAs of up to 8 hours in duration, with one hour of emergency return. This is limited by the oxygen supply of the spacesuit, and to prevent any emergency, oxygen bottles will be installed in any used lunar vehicle as backup gas tank. They will have an amount of one hour of duration.

Additionally, the suit has the ability to operate for up to 2 hours of continuous exposure in a shadowed area, including Permanently Shadowed Regions (PSRs). This feature is especially important as it allows astronauts to explore areas that receive little or no sunlight. With that, exploration during lunar night and inside lunar craters will be possible.

One of the last important information is that the suit will be pressurized and withstand pressures ranging from 0.4 psid to 8.2 psid. The nominal EVA pressure is 4.3 psid (30kPa), which provides an adequate level of safety and comfort for the astronauts.

2) Mobility: As stated before, the spacesuit has been selected for its better mobility. Astronauts will be able to traverse through different terrains by walking, crawling, and scrambling on hands and knees. The suit is designed to allow astronauts to walk across a slope of up to 20°, and on traverses of up to 2 km away from the lander. Exploration excursion for more than 2km can be done with rovers.

Astronauts will also be capable of traversing into and out of craters, volcanic terrains, and shadowed regions. Carrying tools may be required during EVAs, attached directly or via a harness, to assist astronauts in their tasks.

3) Radiation Shielding: As stated before, radiation on the moon can be damaging for astronauts, especially during EVAs. They must be protected against it to prevent any health problem linked to radiation exposure.

Different techniques can be use to protect astronauts and electronics devices from radiation, shielding, reduce exposure outside, and biomedical countermeasures. All are currently under research.

Radiation coming from the sun, such as solar winds and solar flares may be the easiest to be protected against. Improved comprehension of how the sun influences the deep-space radiation environment is crucial, as solar activity has a significant impact on it. During all four Artemis mission, plenty of research will be done on the radiation exposure on the lunar surface. For instance, during Artemis I, Orion was carrying radiation monitor from NASA ans ESA[28], and a shield from a company called AstroRad. These data are priceless to adapt the spacesuit to optimally protect astronauts during EVAs.[29] AstroRad is a company that designed a radiation protection vest, especially against solar radiation.[30] For the project, it can be assumed that all these data were used to adapt the spacesuit to give to astronauts a complete protection against Solar Winds and Solar Flares.

However, the new biggest threat here will be Cosmic Rays. These are much more hazardous and it can't be certain that how these work will be fully understand for 2030. It can be assumed that research will still be under development, with for instance small shields and medication, but it is not enough to assert that astronauts will be protected. The best way to protect astronauts will be to reduce number of EVA during the time where solar activities are low. A interesting fact is that cosmic ray exposure is related to the solar cycle. With very low solar intensity, cosmic rays easily infiltrate the Sun's magnetic field, which leads to more cosmic rays. By avoiding EVA during solar minimum of activity, astronauts will be less exposed to this radiation.

But this field of study will be important on the lunar base, because avoiding all these radiations is crucial to go to Mars.[29]

4) Dust Protection: Lunar dust poses a major challenge to the integrity of spacesuits as its coarse texture can cause damage to the inner layers. To prevent that, the xEMU suit has been designed with measures to stop the entry of dust into the suit by minimizing the number of suit parts that could allow dust ingress.

As an example, the helmet assembly will have two dust filters to prevent lunar particles from entering between the visor and the helmet.[31] Moreover, the upper and lower torso have some changes in the joint bearings, especially in the shoulders and knees area. Lunar dust used to be trapped in these components, and that is why it was important to use Lunar Dust Removal techniques in these specific locations with meticulous attention.

E. Lunar Vehicles

1) Requirements: The different lunar vehicles that are going to be brought as a payload on the Moon will be alongside the astronauts on some EVAs to help them perform the tasks they have been assigned. On some other missions, the rovers will be controlled remotely from the station to perform some specific tasks. In this perspective, there are requirements in terms of mobility as they should be able to go upon rocky terrains or down some craters, of reliability as the astronauts should be able to count on them, and also of performance: the longer the rovers will be able to go away from the base, the broader the exploration field is and then the higher chance of interesting discovery there will be.

Firstly, some manned rovers are presented, both pressurized and pressurized. Secondly, several unmanned rovers designed to perform some specific tasks are covered.

2) Pressurized rovers: Lunar Cruiser. The main advantage of having a pressurized rover is that it expands considerably the length of the EVA, enabling then to go further away from the base than with a classic vehicle. This kind of rover typically contains a pressurized compartment that can be powered by fuel cell technology.

The Japan Aerospace Exploration Agency (JAXA) has recently reached an agreement with the Japanese automotive manufacturer Toyota to develop this kind of vehicles [32]. This ”Lunar Cruiser” (Figure 6) is planned to be launched in the latter half of the 2020s, and would be able to run for 10,000km. It is powered by the same hydrogen fuel cell technology found in the existing Toyota Mirai. Being 3m tall and 5m long, it can travel up to 10 km/h over rocky terrains. Containing two beds and a toilet, there is enough room for 2 astronauts that can travel across the moon for up to 45 days.

If only one rover is used, it cannot go further away than 10 km from the base. Indeed, in case of failure, the astronauts using it should be able to come back by walking. This is why 2 rovers are needed. If two are going away side by side, the range could be increased to 100 kilometers.

This 100-kilometer range can be highly interesting for science and more specifically to study radio waves in the far side of the moon.

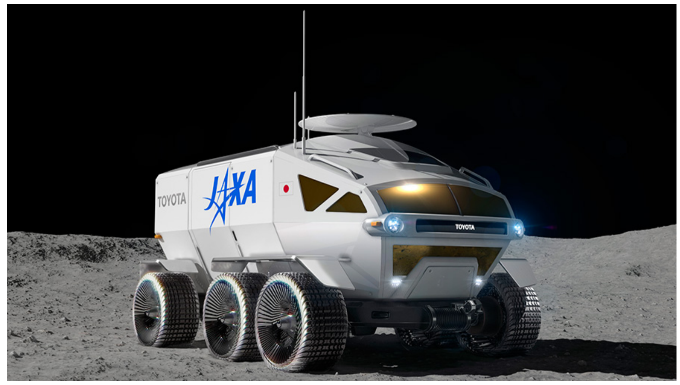

Fig. 6: JAXA/Toyota pressurized rover ”Lunar Cruiser” [32]

3) Unpressurized rovers: Lunar Terrain Vehicle (LTV). Planned to be operational in the mid 2020’s, it can traverse 20 km in a single charge. Its nominal transport weight is 800 kg (550 kg corresponding to the crew and 250 to payload) and its logistic transport weight is 1600 kg. Indeed, it is operable on-board but also by remote crew. It is can be used over a maximum slope of 20° and in case of complete shadow, it can operate for at least 2 hours. Moreover, it can support 8 hours of EVA, carry a robotics arm manipulator for science exploration. However, as it is single fault tolerant against catastrophic hazards, it is decided to have 3 versions of it on the lunar surface. 2 could be used simultaneously and one would stay close to the station as a back-up rover.

Fig. 7: Artist’s impression of the LTV [33]

IV. Schedule

A. Monthly considerations

It is a complex task to precisely determine what will look like the monthly schedule of the lunar base. However, we can already draw some categories of activities. One particular point to take into account is the lunar day: most critical actions might be preferable to be achieved while there is sunlight (to benefit from a better visibility and power from solar arrays).

- Maintenance: taking care of the station will require several points to regularly check and correct if needed, such as regolith shield on the base, maintenance on vehicles (autonomous rovers and non-autonomous rovers), cleaning garages and other ”open” spaces, changing tanks or batteries, cleaning arrays (1200m^2) and antennas.

- Receiving cargos (every 3 months, according to the ”Blue Logitistics” sub-group from this project) and managing the waste on a regular basis.
- Science: as chosen for this mission, the main topics will be agriculture, radiation study, geology, seismology, propellant research and testing technologies for further missions. These scientific studies won’t be prioritized in the schedule (they will come after all the essential activities to maintain activities on the Moon), and will depend on the state within the lunar day.
- Leisure and ”real-life” moments : this point might come last but will have surely its own importance if missions plan to last several months, to keep all the crew mentally safe and a good quality of life [34]. Talking with the relatives, looking at the window, or even reading… make parts of the astronaut life [35].

B. On a daily basis

For the day to day operations the schedules and work hours of the moon base inhabitants were modelled after the Amundson-Scott station on the south pole. The inhabitants are divided into two groups, those involved with the operations and maintenance of the base and those involved with a specific research project. The group in charge of operations work in three different shifts while the people that work with research projects are divided into teams that follow a specific team schedule. This way the scientist are allowed to focus purely on their research while the continual upkeep of the station is taken care of by the support staff.

V. ”Off-Nominal” scenario

What if… the communication device of an astronaut breaks down during an EVA?

During EVAs, astronauts will form pairs as they already do in every manned mission (on the ISS, in the previous Apollo missions…), for safety reasons : in case of a problem for one of the astronaut, the other then become a great help and insure a high level of adaptability. This is a first common feature with scuba-diving: in this activity every divers need to act in pair, and care about his or her mate, evolving in an environment that can be hostile for humans (no oxygen, pressure gradient, carrying load…).

However, an advantage of doing activities in space with spacesuits is that you can communicate orally with your mate and the Habcom (person responsible for the EVA that remains in the base), thanks to communication devices.

But here is discussed the case where one of these communication devices breaks down, and leave one astronaut without the ability to ear and/or talk to his or her mate.

This is an emergency, the situation goes off-nominal and it has to be safely and shortly brought back to normal. Here is a draft protocol:

*Astronauts **A** and **B** are performing and EVA on the lunar ground. Communication device of A breaks down.*

- Make people aware:

Fig. 8: Example of gestures communication in scuba diving *(from decathlon.com)*

  - Mate (**B**) : this is the first person to call out with gesture or anything that can draw attention, because he will be able to take care of **A**’s problem and also warn the ground control if the communication range allows it. To describe the problem, some basic gestures must be known to describe basic information (as in scuba diving [36], see Fig 8): cannot hear, cannot speak, physiological state… A tablet with a pen can also be used to describe more specific problem.

  - Base : **B** is in charge to warn the ground control as soon as possible, giving clear information about the situation, precising the level of emergency. The ground control must assess the reception and then follow attentively the case.
- Secure:

  - The principal aim is to avoid a multiple accident involving **A** or **B**. All precautions must be taken: stopping current tasks (or at least shortening them as possible), leaving non-essential instruments on site, visual check of both suits and report any anomaly
- Go back safely:

  - Taking the best safety/length compromise path, heading to the base
- Ingress:

  - **B** must serve as a relay between **A** and ground control, especially for ingress and pressurization protocol.
- Post-Emergency:

  - Write a precise fault report, investigate the cause of failure and adapt.

More generally, *”Off-nominal scenari”* must be identified and discussed before the beginning of a mission: quantifying their probability and the risks they can rise. Then, astronauts and ground controls must be trained during the mission’s preparation phase, in order to overcome this hazard when ever they happen. From ”basic training” to ”on-board training” [37], these protocols and skills must be reviewed.

VI. Conclusion

Designing operations for a Lunar Station is challenging. The primary goals for the Lunar operations were to choose the

Fig. 9: Virts, Shkaplerov and Cristoforetti Participate in Medical Emergency Training
(from nasa.gov)

various way of communication, how lunar operation will be conducted at the surface, and the schedule of the crew.

The communication between the Lunar Base and Earth will use the Gateway as a relay, and additional satellite was not required. Three frequency bands have been selected: the Ka-Band, the X-band and the S-band. They have various purposes to fit at all situation that can happen on the Lunar base. The communication during EVA will be different, as it requires more ranges. The use of 4G and 5G was discussed for EVAs further than 1.5km from the Base.

The protocol of EVA was described, with an analysis of the spacesuit and the Lunar Rovers needed. The two main threats on the lunar surface are radiation exposures and lunar dust.

At the end, a monthly schedule of operations was described to explain how the lunar station will be organized. The purpose of the lunar base is to do research on the Moon, which requires well planned operations. This mission will require a lot of research in space technology, and it will be interesting to see this investment. The lunar base can be seen also as the first step for Mars explorations, because various fields of study done on the moon can be adapt to the mars surface. Major breakthroughs are to come, Mars exploration can be seen as the new conquest of this century, it is around the corner!

VII. Division of Work

For the overall project, the division of work is described in Table IV.

TABLE IV: Division of work

	Matéo	**Filip**	**Louis**	**Alexandra**	**Nicolas**
Communication between Earth and the Gateway		X			
Communication between the Gateway and BLISS			X		X
Communication during EVA	X			X	
EVAs : Protocols and Lunar Dust stakes					X
EVAs : Spacesuits and Radiation stakes				X	
EVAs : Lunar Vehicles	X		X		
Schedule (Monthly-Daily)		X			X
"Off-Nominal" Scenario					X
Peer Reviews	X		X	X	X

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