BLISS - Base Lunar Installation for Scientific Studies
Overall Coordination

Team Blue

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***Abstract*—Human history and the Moon are a pair never to be separated. The first landing on the moon in 1969 made large progress in space development, and research on the Moon is still in progress. It is 2037, and the Artemis program has been completed with all the goals met. This program has clarified big scientific potential. This report refers to designing the lunar research station, which will be constructed after the Artemis program ends. It consists of five parts. In the introduction part, the mission description will be given first. Location, research area, and logistics will also be analyzed. The method section refers to subsystems after the project management description. Furthermore, social and political factors, off-nominal scenarios, and mission constraints will be mentioned in this order. The results part includes highly important contexts of cost analysis and funding. Finally, it is followed by discussion and conclusion parts.**

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I. Introduction

A. Mission Description

It is the year 2037 and the potential resources on the Moon are getting more attention than before. The Artemis program met all its goals and a Lunar Gateway is already in place. The first people are heading towards Mars, but to ensure a long-term and safe stay for them on the red planet, we need to do research and develop our current technological knowledge with the help of the opportunities given by the Moon.

For this, the Blue Team was tasked to design a lunar research station. This station should be operational from the year 2040 and should be able to host up to 50 people. The Amundsen-Scott Station on Antarctica is used as an example, and we have a smaller temporarily crewed base at our disposal.

The name of our mission is BLISS, which is the acronym for Base Lunar Installation for Scientific Studies. This stands for our mission goal, as the plan is to construct a large research station on the Moon. Our mission patch, shown in figure 1, consists of several symbols representing our mission. The black oval part around our acronym represents the Shackleton Crater, the location of our station. The Moon is right behind the crater, while the stars and dots stand for the different researches that we are planning to do during our stay on the base.

Figure 1: BLISS mission patch

B. Location

We considered a few important parameters for choosing a location, such as the possibility of using solar power, flat surface and the presence of water nearby. An opportunity to have better communication was also mentioned as a relevant factor. It was soon decided to choose the location near the South Pole, as the area there is rich in both water and solar resources.

The first location that was chosen was the Shackleton Crater Site 004. The Shackleton-de Gerlache Ridge area is perfect for having water resources and also to use solar power. Site 004 is based on the ring of the crater, but because of that, slopes can make it harder to perform EVAs and use rovers. Furthermore, water is not so accessible from this location. Therefore, Site 001 was chosen as our final destination, as it is approximately 10 km away from the ring. The exact location can be seen in figure 2.

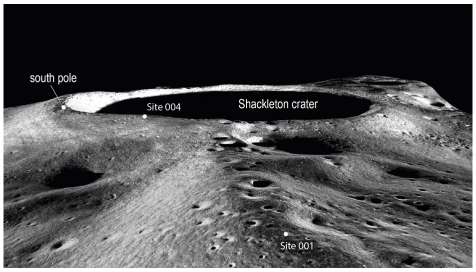


Figure 2: Location: Site-001 Shackleton Crater

C. Research Areas

As our main purpose is to gain knowledge by performing various types of research, different research areas were suggested by the groups within the Blue Team.

An interesting and useful research would be the investigation of the effect of long-term radiation exposure on the human body. The result we get here would lead to more understanding regarding missions to other planets as well, such us the current Mars programme.

The second research area is connected to agriculture. This includes soil research, the behaviour of plants and the way we are able to grow them in an environment different from Earth's. This is also crucial for obtaining life during interstellar missions.

The third research area the base station should provide capacity for is propellant research. As we are going to and back from the Moon, travelling to Mars and hopefully back from there as well, aiming to go even further in the future, it is important to redefine the propellants we use for our rockets and other vehicles. We aim to develop and research new ways of propellant usage, including new Lunar materials for the process if possible.

As the fourth research topic, geology would help us understand the structure of the Moon and the resources it can give to humankind. It can also give us a wider picture of the formation of the Moon. The history and the technological knowledge that we gain there can help us develop technologies for future missions and understand the formation of celestial objects.

Last but not least, our fifth research area will focus on the Lunar core. The fact that we are going to build a research station on the Moon can give us the opportunity to expand the current seismic data we have. The information we have so far from observations and Apollo missions can be enlarged by our constant presence on the object.

D. Logistics

1) Transportation between Earth and Moon: Starship is selected as a launcher vehicle to the Moon. It has a capacity of 1000 m^3 and 100 tons budget, which is enough for this project. The cost of 10 million $ is cheaper than other vehicles. [1] The number of launches and the amount of payload is mentioned in the section on constraints.

2) Transportation on the Moon: Paved roads constructed with the ATHLETE rover are the basic way of transporting on the Moon. Along the roads with lights, vehicles for any supplies and extracting activities can move safely and smoothly.

3) Development of Resources on the Moon: One of the most important resources is water and there is at least $600 \times 10^6\,\mathrm{m}^3$ water on the moon. [2] The establishment of water production with several rovers enables people to run the project in long term. In addition, other resources are buried but essential to introduce much more infrastructure.

4) Timeline: This project is divided into two phases. The first part is the settlement phase. The main mission of this phase is to construct the station and infrastructure. In addition, this phase includes the realization of a solar power system and the establishment of a permanent crew. The next phase is the full operativity phase. To continue the mission, crew changes and resupply will be conducted.

II. Methods

A. Project Management

The Blue team consists of 23 members with 5 subgroups, to maintain consistency efficiently with such a large group requires a heavy emphasis on project management. The primary goal of project management was to ensure that every sub team works together with the same set of assumptions and calculations to avoid conflicts in information. First the Overall Coordination team set up a Gantt Chart (Appendix) to map out the key deadlines and scheduled meetings over the course of the entire project. This chart includes deadlines for each individual sub team to ensure that every group moves forward at the same pace. Additionally, deadlines for tasks to be completed before group meetings was readily available to all team members. This Gantt Chart was periodically updated throughout the project as changes were made to deadlines and tasks.

The Blue team had 8 scheduled full team meetings over the course of two weeks which were primarily used to communicate progress with other sub teams. Meeting notes were taken by Overall Coordination for each of these meetings for any members who were absent during the large team meetings and for future reference. The large team meetings were structured according to the Gantt Chart with the first two mostly consisting of house-keeping and deciding on initial choices for the project such as landing location.

Communication outside of these meetings was done via Slack and a shared Google Drive. Multiple channels on Slack were created such as a full team channel, one for each subgroup as well as a channel with an elected team leader from each subgroup. The google drive was shared with everyone for documentation of their work and sharing important spreadsheets and templates. A Google Spreadsheet for important calculation values from each member was compiled into a larger sheet to ensure all values are consistent as well as a sheet for any members to submit questions to other groups outside of meeting times.

After the first initial meetings, the Overall Coordination team implemented a more structured meeting plan as each group progressed with their work. This followed the general schedule below:

Table I: General schedule of team meetings

Time	Plan
10:15 – 10:30	Summary from each group on the progress from the last week, and overview of plan for today's meeting
10:30 – 10:45	Any planned full team discussions according to Gantt chart or presentation from a subgroup – otherwise move onto multi-group discussions
10:45 – 11:45	Multi – group discussions
11:45 – 12:00	Summary from each group on the progress from the discussion during today's meeting, and any deadlines or future work for next meeting

The multi-group discussions were organised by Overall Coordination where the subgroups were paired together to further progress their work and confirm any calculations. Towards the final few meetings however, the multi-group discussions became less structured and allowed for each group to talk to as many other groups freely as required to progress on their work.

A progress check meeting was also held which consisted of a small overview presentation of what each subgroup had worked on so far. This allowed for the other subgroups to gather any information needed in a time efficient manner as well as allow for any questions or comments to be presented to the subgroup for them to then further work on.

Outside of these large team meetings, each subgroup also had separate smaller meetings to work on their responsible parts. Meetings notes were taken during these and shared with the rest of the team for any cross referencing if necessary.

B. Subsystems

The blue team has a total of 23 members with 5 subgroups of 4 to 5 members – Overall Coordination, Logistics, Operations, Station Design and Human Aspects. Each subsection is responsible for a certain part of the mission which was decided initially in the first team meeting. Due to overlapping responsibilities in sections however team meetings frequently involved one or two subgroups having a discussion on progress. Additional to the individual responsibilities, each subgroup came up with a unique off-nominal case and potential solution for this problem.

1) Overall Coordination: The objective of the Overall Coordination group is to organise and manage the tasks and functionality of the entire team by leading team meetings and supporting communications between other subgroups. Additionally, the Overall Coordination group ensured that each subdivision was working in the same direction simultaneously by creating a timeline for the entire team via use of a Gantt Chart and an organised meeting agenda for each week. Besides the organisational aspects of Overall Coordination, the group was responsible for the risk analysis, cost estimations and consideration of the social and political aspects of the mission with particular focus on funding of the mission.

2) Logistics: The objective of the Logistics team is to research and select launch vehicles for the missions and determine the flight trajectory and landing position for the mission. Additionally, the Logistics team determines the balance between resupply and recycling for the mission and the optimal payloads for launches to maximise efficiency and reduce unnecessary refuelling costs. The Logistics team is also responsible for organising any rovers and transportation on the surface of the moon and the in-situ research such as mining and water production.

3) Operations: The objective of the Operations group is to organise the routine operations on the mission, covering tasks such as daily and weekly maintenance and research development sections and the communications on the base. The Operations group works closely with each group to ensure their needs are met and upkept in the long-term scope of the mission. Additionally, the choices of spacesuits and protocols for EVAs are organised by the Operations team.

4) Station Design: The objective of the Station Design group is the create the architecture and construction of the primary base and the exact location. Station Design is also responsible for exploring the power and thermal aspects for the mission and radiation protection of the base. The Station Design group worked closely with the Human Aspects group to ensure that safety procedures can be implemented in the base's design.

5) Human Aspects: The objective of the Human Aspects team is to create the life support systems in place for the mission ranging from recycling of waste to how to perform EVAs. Additionally, the safety and medical aspects were often communicated with operations to ensure smooth function of procedures on mission. Both the short term and long term health and safety aspects were considered for both physical and psychological wellbeing. Additionally, the Human Aspects team is responsible for oxygen, food and water production and recycling on the lunar base.

C. Social & Political factors

Establishing a more permanent base in another world will most likely have an impact on life back on Earth, whether this be in research, socio-cultural aspects and cost of future space missions. Building a lunar base is the next step in establishing a more permanent human presence in space, while at the same time enabling future space explorations by being a "stop on the way". A lot of resources and time is therefore being devoted to research by space actors to investigate how this can be implemented. For instance, NASA has awarded the Austin based company ICON a $57.2m contract in order to investigate lunar construction technology [3]. This project is planned to be carried out after the Artemis program has successfully been concluded with all goals met of that program. This means that the goal of having longer human presence on the Moon is met, and now it is time to take the next step to not just survive, but also make use of the unique research possibilities that can be carried out on the Moon.

1) Social factors: Given that the primary source of funding for this project is meant to come from governmental support, meaning taxpayers money, it is important to have the public's support. Without the public's support, the project risks being seen as illegitimate and may loose its funding. To withhold a positive public opinion regarding this project is therefore substantial for the project's longevity. Things that might affect the public's opinion are plenty. A deadly disaster, similar to the Challenger explosion in 1986, could make people question the safety of the project [4]. If the project is very expensive and believed to not be cost optimized, it can be seen as a waste of taxpayers money. Lack of public involvement could make people feel that while they are paying for it, they are not able to take part in it or reap any (visible) rewards from it. Speaking of rewards, with a permanent base on the Moon humanity is taking yet another step towards colonizing space. With this comes a lot of juridical questions. One of them is how to handle the question of globalism in space. With an increased human presence in space, it is not unthinkable that we will soon want to make use of the resources available in space. NASA is investing in companies aiming at exploring lunar craters and the possibility to mine asteroids [5]. Taking advantage of the available resources in space can help with the solution to some of the problems here on Earth, an example is regarding mining minerals important for the transition to a more environmentally sustainable society [6]. Another example is making use of the resources in space to build infrastructure while humans are further exploring space. However this raises the question regarding who can claim ownership of the resources available to mine [7] . While this question has been raised and addressed in some instances, there is still no clear regulation regarding how this should be handled and is for the moment dependent of the rather vague formulation in the Outer Space Treaty. [8] [9]. While an increased human presence may result in some difficulties, it may also be an opportunity to increase international cooperation. An example of this is of course the ISS [10]. Another thing to comment upon is who is driving the exploration of space. During the cold war it was mostly governments behind space exploration projects. With today's rapid development of space companies taking a bigger share of the investments put into space, this might affect how space exploration is conducted.

2) Political factors: The political aspect of establishing a more permanent research base on the Moon is immense. It can be seen in the light of a modern day space race, since establishing a permanent base on the Moon will inquire questions regarding the symbolic ownership of the land. However, due to the Outer Space Treaty [11] from 1967, no state can make territorial claims or prevent another nation from accessing the space or a celestial body. However, one should not ignore the symbolic value in this situation. Especially since space exploration during the cold war was a way to show off power towards other countries. This fed a new type of nationalism where showing off successful space programs was both a way to unite a country's people as well as showing of towards other rivaling countries their technical progress (ref). This was especially important since this technology can both be used for great things such as sending humans to other celestial bodies, as well as used in military systems, which pose a threat towards potential enemies.

This project is supposed to be supported by a multi-governmental organisation, similar but not identical in structure to the organisation behind the ISS. While this project hopefully can contribute to developing meaningful and stable relationships between countries, it is also at risk of being a brick in a political game.

Since the project will largely be funded by the government, meaning taxpayers money, this might be seen as controversial by some. The project therefore needs to be well motivated as in terms of why the money should be sent on this project while there is starvation, poverty and other pressing issues to be solved here on Earth. As mentioned under social factors, without the public's support the project's funding might be at risk. Therefore it is essential that the project is seen as valuable and producing either social pride, valuable research or something else.

D. Off-Nominal Scenarios

An off-nominal scenario is an unplanned event that can impact the planned mission progress, the crew safety, or the outcome of the programme. Although they are unplanned, some of them can be solved by immediate planned response.

As running a large project in collaboration with different nations and companies, we should consider some of the weaknesses these collaborations have. We prepared two off-nominal scenarios, where we describe situations that can occur during the programme, and also recommended solutions for them.

Communication and coordination among the partner agencies would be critical in an off-nominal scenario. The partners would need to work closely together to develop a plan for managing the situation, including communicating any changes in the station's schedule or operational parameters to the crew on board the station.

1) What if a nation/partner leaves the project?: If a nation were to leave the Lunar Research Station, it would mean that their contributions to the station would no longer be available. This could potentially impact the station's ability to carry out scientific research, perform maintenance tasks, and provide for the needs of the crew. It could also create challenges in terms of communication and coordination among the remaining partner agencies. In this case, there need to be a coordinated response among the remaining partner agencies to manage the situation.

The first step would be to assess the impact of the nation's departure on the station's operations and crew safety. The remaining partner agencies would need to determine whether the station can continue to operate safely and effectively without the contributions of the departing nation, or whether changes need to be made to the station's schedule, crew assignments, or other operational parameters.

Depending on the situation, the remaining partner agencies may need to take on additional responsibilities to ensure the continued operation and maintenance of the station. This could include providing additional crew members, hardware, or supplies, or taking on new roles in scientific research or maintenance activities.

As an example for a possible solution, we are planning to have the most important back-up technologies among different nations, such as cargo spacecrafts, or launch vehicles, in order to maintain the crew's safety. This can be accomplished not just by the help of the nations involved, but also by outsourcing crucial parts to private companies.

Another solution would be to establish an agreement among the partners. This would state that at least one year's prior written notice is needed in case of withdrawal. This would give us enough time to prepare for the changes. The agreement would also contain the list of necessary items and documentation that will be required from the leaving partner to provide. This solution was inspired by the Agreement Between the United States of America and other governments regarding the International Space Station [12].

2) What if we run out of money to cover the project?: Another risk can be the absence of money in our budget for the estimated costs. This can be caused by global events that affect the economy, or by losing a potential financial partner. In the case of not having enough financial background to cover the project, the worst case scenario is that the programme has to be turned down in order to insure the safe return of the current lunar crew.

As a solution for this problem, we are planning to have escape launchers on the Moon, in order to be able to return everyone to Earth. A launch vehicle will already be available for them, as they can use the one they used for getting to the Moon, but in case something happens to that, an extra vehicle can be used.

If it is not possible to do the launch from the Moon, and we have to launch from Earth, we are planning to save a buffer budget that should cover the necessary operations of returning everyone safely if it has to be done from Earth. To reach this, we will save 30 million, which will ensure everything that is needed for the trip to the Moon and back.

E. Assumptions & Constraints

The major mission constraints come from the project's instruction. We assume the year is 2037. Then, as the assumption of situations, a lunar gateway exists, a launcher such as Starship is operational, and small human habitats exist on the lunar south pole. From those assumptions, the following two Mission constraints for the overall mission are made.

- The research station needs to be operational in three years.
- The size of the station is large enough for up to 50 people to live.

In addition, considering each objective and responsible part of the subsystems, more specific constraints were made. One of the most important constraints is payload mass. Regarding station design, a minimum of 464 tons of materials are needed to construct the lunar research station. It means that the launchers must be capable of carrying at least 464 tons in total, which is also a significant constraint for the logistics part. To satisfy that, two types of launch strategies are considered. One of them uses six spacecraft, and each one can carry 100 tons. Another one uses 16 spacecraft, and each can carry 35 tons and come back to the Earth for reuse. These two cases were estimated to load additional budgets.

Likewise, there are other constraints in terms of the station design section. The full construction of the research station must be finished in three years. All functions and facilities must be completed as soon as possible to operate the station smoothly.

The second one is also a crucial point for the human aspects part. This constraint comes from the consideration of influences by radiation. The station is required to have sintered regolith shields with a 4m width for preventing radiation under 20 msv per year. Originally, the width of 6m is necessary to live without harm by radiation when using regular regolith, but solar sintering 3D printer enabled to minimize the width. The construction of the shield also must satisfy the construction period of three years. On the other hand, assuming the activity time of EVA is five hours per day, the maximum stay on the moon before full construction is achieved is limited to 7 months in terms of human aspects.

Furthermore, another highly important constraint involves logistics and human aspects. This project is planned for the long term, and the establishment of a system of water production is mandatory. The estimation of how much water can be produced is about 500 kg per day. From the human aspect, the life support system needs a significant amount of water. Including the supplement from the earth, this system is required to make the best of those supplies.

III. Results

A. Initial Cost Analysis

The cost estimate of the mission is divided into two parts, initial costs and running costs with more specific categories within both parts as analysed in this section. The cost estimating process follows that of NASA's cost estimating handbook (CEH) [13], the two primary methods used in this estimate is the analogy and parametric method.

The analogy method is primarily used in the concept and development phase of a mission while the parametric method is primarily used for the design phase. The analogy method uses costs of a similar system with adjustments for differences to estimate the cost required for the new system. The benefits of this method is that it is based on historical data and is accurate for minor deviations from the analogy however it can be difficult to identify an appropriate analogy and often relies on a single historical data point which may lead to inaccuracies. The parametric cost estimates are based on statistical relationship between historical costs and other program variables.

The initial cost of the base covers single upfront costs required for the building of the base and the cumulative costs over the first 3 years such as salaries during the construction phase. This total then comes to 32.8 billion dollars with a general cost breakdown in the table below.

Table II: Initial Cost Estimate Summary

Category	Cost (Million $)
Development & Testing	1609
Payload & Launch Vehicles	27042
Project Management & Operations	1311
Safety & Mission Assurance	590
Science & Technology	806
Education & Public Outreach	39
Ground Facilities	1377
TOTAL	32792 ($32.8B)

Of these categories the 3 of them were calculated with the parametric cost analysis method. The following percentages were calculated according to the cost breakdown of the Apollo program (1960-1973) [14].

Table III: Percentage of Budget

Category	Percentage
Development & Testing	5%
Education & Public Outreach	0.1%
Ground Facilities	4.3%

The operations cost for the construction phase is calculated in a similar manner however instead of being a percentage of the total initial cost it is three times of the yearly running cost calculated in the next section. This is done since a portion of the operations costs in the initial years overlaps with the development and testing costs and therefore can be reduced in the cost estimation.

1) *Payload & Launch Vehicles:*

A detailed cost breakdown of the payloads and launch vehicles and costs can be seen in the table below.

Table IV: Payload & Launch Vehicles Cost Estimate

Item	Cost (Million $)
Base modules	85
Airlocks (x4)	656
Variety of rovers	448
Launches to Moon (x11)	1100
Launches to LEO (x88)	880
Starships (x10)	1870
Starship Maintenance	22000
TOTAL	27042

The base modules and airlock cost is provided from the Station Design team's calculations [15]. The rovers used for construction and research vary in specifics such as being pressurised or unpressurised however for ease of calculation they can all be approximated to be in similar price.The estimate of approximately 56 million dollars per rover is taken from the deal signed between Australia and NASA (50 million) to build a moon rover to collect rocks and oxygen [16].

The launch cost estimates are produced from Elon Musk, CEO of SpaceX who suggests that in the future it will cost 10 million dollars for a launch to LEO [17]. Comparing this to current space crafts which have cost estimates as low as $100/kg for launch to LEO and $1000/kg to launch to the moon [18], an estimate for the Starship launches to the moon can be estimated to 100 million dollars per launch. Both of these estimates however have the potential to decrease by the year 2037 as estimates as low as 2 million dollars for a Starship launch to LEO has been suggested for the future. To maintain the condition of the reusable Starships, 2 billion dollars is required for each launch to the moon.

2) *Safety & Mission Assurance:*

A detailed cost breakdown of the safety aspects and mission assurance can be seen in the table below.

Table V: Safety & Mission Assurance Cost Estimate

Item	Cost (Million $)
xEMU spacesuits (x16)	352
New Moon Duster	78
Life support systems	130
Emergency buffer budget	30
TOTAL	590

The xEMU spacesuits are still under development from NASA having already $420 million on development [19] However, based on the previous generation of suits it can be estimated to $22 million each. Additionally, the new moon duster and other life support systems estimates to 58 and 150 million dollars respectively according to the ISS. An emergency buffer budget of 30 million dollars is also included in this section according to the solution of the off-nominal earlier in this report. This budget is the cost required to safely transport all humans at the lunar base back to Earth in case of an emergency evacuation or cancellation of the mission.

3) Science & Technology: A detailed cost breakdown of the initial science and technology required for the mission can be seen in the table below.

Table VI: Science & Technology Cost Estimate

Item	Cost (Million $)
Agriculture (hydroponics)	8
Agriculture (aeroponics)	10
Sabatier system, water recovery system (WRS), oxygen generation equipment & specialised work-out equipment	460
Masten rocket mining system	98
NASA fission power plant	80
Spectro Lab solar cells	50
Regenerative fuel cell system	100
TOTAL	806

The science of technology cost estimate includes the equipment required for the multiple research areas. The key costs comes from the the combination of the 3 key life support systems and specialised workout equipment. This estimate of $460 million is done analogically compared to the ISS's $250 million home improvement project [20] which includes the same water recovery system we wish to implement. Additionally analogical comparisons for the other technological equipment can be made.

B. Running Cost Analysis

The running cost of the base comes to 10.2 billion dollars per year with a cost breakdown as shown below.

Table VII: Running Cost Estimate Summary

Category	Cost (Million $)
Project Management	6
Safety & Mission Assurance	308
Launch Vehicles & Services	8721
Mission Operations	439
Education & Public Outreach	13
Ground Facilities	733
TOTAL	10219 ($10.2B)

As with the initial costs, the ground facilities, mission operations, education and public outreach costs were determined by the percentage distribution of previous missions. A detailed view of the other categories can be seen in the two sections below.

1) Launch Vehicles & Services: The launch vehicles were calculated the same as in the initial cost analysis however with the adjusted number of launches required for yearly operation after construction.

Table VIII: Launch Vehicles & Services Cost Estimate

Item	Cost (Million $)
Launches to Moon (x4)	400
Launches to LEO (x44)	320
Fuelling	1
Starship Maintenance	8000
TOTAL	8721

2) Safety & Mission Assurance: Safety and mission assurance includes the costs of yearly resupply and maintenance of the xEMU spacesuits. Resupply estimates were gathered from our Logistics team.

Table IX: Safety & Mission Assurance Cost Estimate

Item	Cost (Million $)
xEMU spacesuit maintenance	208
Resupply	100
TOTAL	308

C. Funding

Building a long-term base suitable for human presence on the Moon is not an easy task. Various aspects are to be considered and enough funding needs to be available. In order to secure access to funding, this mission has been decided to be an intergovernmental project where, similar to the ISS, ownership and use of the station is established through intergovernmental treaties and agreements. To minimize the cost, private companies will be able to take part in developing and providing the technology through contracts. Various initial estimations have been proposed by different actors. CSIS proposes that the development of a lunar base is US $35bn, with an operating cost of US $7,35bn per year [21]. Similar numbers have been proposed by NextGen Space LLC (in a study partly funded by NASA); estimating an establishing cost of a moon base at US $50 bn [22]. These numbers are in line with the proposed cost breakdown provided earlier in the report.

As this will be a multi governmental project, this means that the primary source of funding will be government funding.

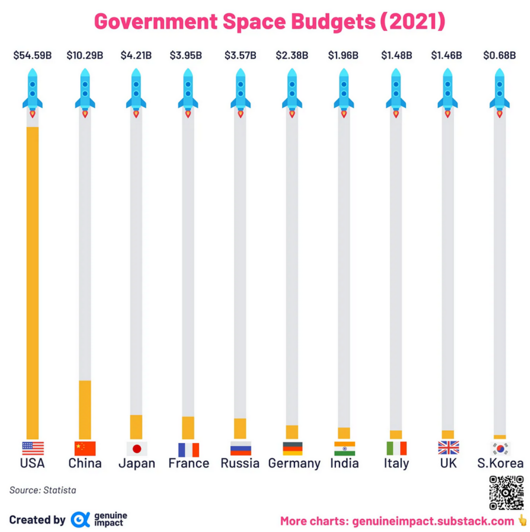


Figure 3: Government Space Budgets 2021

Given the initial cost estimation for this project presented in the previous section, one can see in figure 3 that this project would take up a big share of the current size of space budgets, and is thus not reasonable to believe to be carried out by only one country. By combining the budget for the mentioned 10 countries, one totals at US$83,11bn. The space budget for each country is also distributed among various different activities, an example is how the NASA budget was distributed in 2022, seen in figure 4. Therefore the true combined budget for these 10 countries on this kind of project can not be estimated to be around US$83,11bn by only looking at the total space budget. An increase in the space budget for the participating countries would therefore be necessary. How big the increase has to be is of course dependent on which countries are interested in participating.

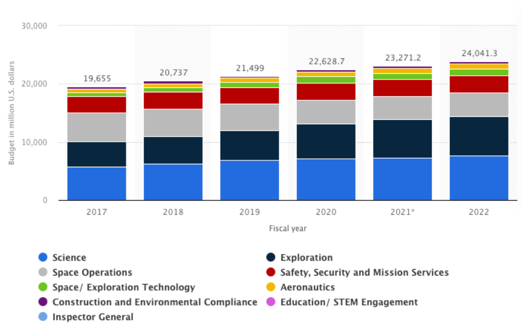


Figure 4: NASA funding breakdown

To compare with a previous and similar space project, one can mention the ISS. The construction cost of ISS came out to US$150bn, and has an average operating cost per year of approximately US$3bn [23] [24]. This cost is divided among the member states, even though NASA pays the largest share [25]. While the lunar base would have a higher operating cost per year, the building cost is at estimate significantly lower. Given the successful history of ISS this is a suiting alternative for the lunar base. How much each country should participate to be a part of this project is up to discussion and can be divided based on later access to the station in terms of crew.

To keep the cost down, using private companies for the development and operations has become more and more popular [26] [27]. The use of private companies in space exploration is an excellent way of reducing the cost. By consulting private companies this doesn't only create jobs, it also has the benefit creating multiple different solutions to building the lunar base, increasing the possibility that the best and most cost efficient way will be used.

1) Other types of funding: While the biggest share of funding is planned to come from governmental support, there is of course multiple possible ways to help fund this mission. One example could be to provide a leasing space for different research institutes, who by having research in the existing facilities in the lunar base will pay a fee. This kind of co-operation with the private industry is therefore a possible way to help support the project financially.

These sources of funding are more unreliable however, and can not be seen as guaranteed.

D. Risk analysis

In conducting a risk analysis, the primary concern is to prevent the loss of a crew member. This entails implementing various safety measures to minimize any risk that may arise during the mission. One essential step in risk analysis is to identify how the risks differ from those encountered on Earth. One of the critical parameters in this regard is radiation exposure, which is higher on the Moon since it offers less protection than Earth. Patrik Sundblad's lecture during the course graphically showed that radiation exposure increases the risk of cancer, as it can be seen in figure 5 [28]. Therefore, minimizing radiation exposure is crucial.

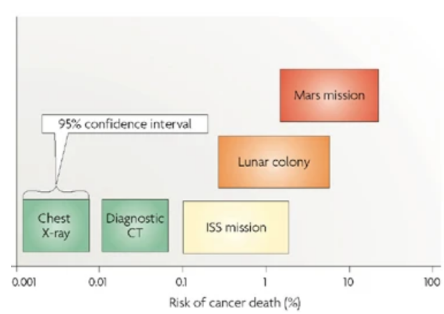


Figure 5: Risk of cancer during long-duration human space exploration

The event of technological breakdown is a risk that must be minimized. This is mainly done by constantly monitoring the technical systems, warning systems, and duplication of crucial system.

Another crucial consequence implemented based on risk analysis is a code of conduct, resulted in a 'zero-tolerance policy', which is inspired by the Amundsen-Scott South Pole Station and the ISS. This policy mandates that minor injuries should be tended to promptly in order to prevent them from escalating into major problems. Furthermore, any misbehaviour that threatens the safety or the survival of the crew members is not tolerated. Since the mission requires crew members to depend on each other for survival and company, any action that jeopardizes this is unacceptable.

Apart from the technological risks, there are also human risks that are harder to prepare for and prevent. One such risk is the possibility of a crime being committed. Handling a crime in space presents unique challenges, such as determining which laws to follow and how best to handle the situation. For this, the development of space law will be essential for the mission.

A few examples can be seen in table X for disruptive events that could occur during the mission. Their likelihood and severity is rated from 1 to 5. These are just some examples of unfortunate events, but the full list for a lunar base station mission would be longer.

Table X: Likelihood and severity of risks

Event	Likelihood	Severity	Total
I Radiation exposure	3	5	15
II Breaking zero-tolerance policy	1	2	2
III Committing a crime	1	4	4
IV Death	2	5	15
V Failure of delivering resources	2	2	4
VI Overshoot budget	4	2	8

According to their likelihood and severity, the events can be displayed in a risk matrix, in table XI. Here the green cells stand for low risk, the yellow ones for medium risk, orange is high risk, and red means very high risk.

Table XI: Risk matrix

		Likelihood				
		1	2	3	4	5
Severity	5	5	IV	I	20	25
	4	III	8	12	VI	20
	3	3	6	9	12	15
	2	II	V	6	8	10
	1	1	2	3	4	5

In conclusion, long-term radiation exposure is the most significant risk to consider for the crew during the mission. Having enough money to complete the mission and a zero-tolerance policy are essential measures taken to ensure the safety and survival of crew members. However, the human aspect poses challenges that are harder to prevent and prepare for, such as handling a crime or other human related risks.

The biggest risks against the mission in itself can count as social and political factors, followed by logistics. Not having enough money for the project is a scenario that could jeopardize the whole mission, but doesn't have to result in any casualties. Failure in the supply chain might pose a risk to both the crew as well as to the base itself, depending on the cargo. Accidents such as a fire or significant technical errors that severely changes conditions within the base (e.g. such as a depressurization) pose a threat to both the infrastructure as well as the crew.

IV. Discussion

Through the instructions and the contents we talked about with each subgroup, some momentum assumptions and constraints were made. When it comes to some of them, discussions are needed in the case of worse scenarios.

The most significant assumption is the existence of a lunar gateway. According to NASA, assembly of the gateway will begin in 2024 and be completed in 2026. The orbit of the gateway is the near rectilinear halo orbit, called NRHO, which enables the communication between the Moon and the Earth because the orbital plane always faces the Earth. [29] Moreover, the long orbital range of the Moon from the orbit allows for smooth communication with the lunar research station to be established at the South Pole. Suppose a gateway is not clearly available by 2037. In that case, it will be necessary to select a communication or transportation method that does not use the gateway or revise the schedule.

The second assumption to be discussed is about the Starship. The BLISS project will use SpaceX's Starship as the launch vehicle. Considering the number of people required for the research station, the development cost, and the payload mass for the station construction between 2037 and 2040, we concluded that the Starship is appropriate for this project. The conclusion was that the Starship was the right choice. The launcher has been flight-testing at low and high altitudes through prototyping since 2019. Then, a flight test to orbit is scheduled before April 2023. [30] Therefore, at this stage in 2023, it cannot be assured that it will be fully available for the lunar research station construction mission. If there are delays in the development of the launcher vehicle, it will be necessary to consider spare launcher vehicles from among the launchers available at this stage.

Another assumption is establishing a water production method at the lunar research station. According to NASA, there is a lot of water on the Moon, most of it at the South Pole. The lunar research station will be built at the south pole to facilitate water availability and continuous activities. The project will be tested on Earth between 2020 and 2025, and a rover will extract water on the Moon between 2025 and 2035. [31] If sufficient water cannot be extracted with the rover technology, securing water by other means will be necessary. One of them is transporting water from the Earth, which would be costly. Furthermore, the water that can be extracted from the area around the south pole may not be sufficient, and much extraction work may be required at other locations. In that case, the development schedule should be revised to include more rovers and more people to perform the extraction work.

V. Conclusion

A. Future Work

There are several potential future work ideas that could arise from constructing a lunar base station. Here are a few possibilities for how to continue our work after we succeed project BLISS.

A very important aspect would be to explore the long-term sustainability of the lunar base station: As the station becomes more established, it will be important to consider its long-term sustainability. This could involve researching and developing new technologies for recycling resources, managing waste, and generating power on the lunar surface. If we are able to solve these problems up on the Moon, that could lead to solutions regarding these problems on Earth as well. As a consequence, it would also be interesting to try to extend the limits of self-sufficiency, and also to decrease costs with the new methods.

The lunar base station could serve as a stepping stone for further exploration and development of the Moon, so we could investigate the potential for expansion. Future work could explore the feasibility of expanding the base station or establishing additional stations in different locations on the moon.

Communication with Earth will be a critical aspect of the lunar base station's success. For this, future work could focus on developing new ways to communicate with Earth, new communication technologies that are more efficient, reliable, and secure.

If there is an interest in it, we will explore the potential for commercial applications. The lunar base station could provide a platform for a range of commercial activities, including mining, tourism, and research. Future work could investigate the potential for these activities and explore the economic viability of different business models.

The establishment of a lunar base station could have significant environmental impacts on the moon. Future work could evaluate these impacts on the environment and develop strategies for minimizing them. This could involve studying the effects of human activity on the lunar surface, as well as assessing the potential for contamination of the moon's environment.

These are just a few examples of the many potential future work ideas we will be able to develop from project BLISS.

VI. Division of Work

A. Alexandra Wu

Sections written: Project Management, Subsystems, Initial Cost Analysis, Running Cost Analysis

B. Kota Koyano

Sections written: Abstract, Logistics, Assumptions & Constraints, Discussion

C. Sandra Robson

Sections written: Social & Political Aspects, Funding, Risk analysis

D. Eszter Szabó

Sections written: Mission Description, Location, Research Areas, Off-Nominal Scenario, Risk Analysis, Conclusion

References

[1] Spacex starship service to earth orbit, moon mars and beyond. [Online]. Available: https://www.spacex.com/vehicles/starship/

[2] Nasa radar finds ice deposits at moon's north pole. [Online]. Available: https://www.nasa.gov/mission_pages/Mini-RF/multimedia/feature_ice_like_deposits.html

[3] (2022) Austin-based icon awarded 57.2 million usd nasa contract for lunar construction tech. [Online]. Available: https://techcrunch.com/2022/11/29/austin-based-icon-awarded-57-2-million-nasa-contract-for-lunar-construction-tech/?guce_referrer=aHR0cHM6Ly93d3cuZ29vZ2xlLmNvbS8&guce_referrer_sig=AQAAAG58EkkQztzJAR5DMzLJHJDqxMg8LXTPsgCc8XaJruq5VPuX9n3zpgXBf2Oh2X6azveRAh2JJ62Ce32BtAEgmEKJI71kp7_OFYBdKcGFERXtQfDe1uSsgD17bJhaal3k89Pm_y1A1RT-ArlX7f7XUQyl5pAKqv6QwG9u6fSTtNMf&_guc_consent_skip=1679229284

[4] The challenger accident and public opinion: Attitudes towards the space programme in the usa. [Online]. Available: https://www.sciencedirect.com/science/article/pii/0265964687900099

[5] (2019) Nasa invests in tech concepts aimed at exploring lunar craters, mining asteroids. [Online]. Available: https://www.nasa.gov/press-release/nasa-invests-in-tech-concepts-aimed-at-exploring-lunar-craters-mining-asteroids

[6] (2016) Framtidens mineralutvinning i rymden. [Online]. Available: https://www.ltu.se/research/subjects/Rymdtekniska-system/Nyheter/Framtidens-mineralutvinning-i-rymden-1.159564

[7] (2019) Vilka lagar gäller i rymden? [Online]. Available: https://www.aktuellsakerhet.se/vilka-lagar-galler-i-rymden/

[8] (2015) H.r.2262 - u.s. commercial space launch competitiveness act. [Online]. Available: https://www.congress.gov/bill/114th-congress/house-bill/2262

[9] (2015) Mining outer space may be cool but is it legal? [Online]. Available: https://room.eu.com/article/mining-outer-space-may-be-cool-but-is-it-legal

[10] International cooperation. [Online]. Available: https://www.nasa.gov/mission_pages/station/cooperation/index.html

[11] (1967) Treaty on principles governing the activities of states in the exploration and use of outer space, including the moon and other celestial bodies. [Online]. Available: https://www.unoosa.org/oosa/en/ourwork/spacelaw/treaties/introouterspacetreaty.html

[12] (1998) Agreement between the united states of america and other governments. Article 28. [Online]. Available: https://www.state.gov/wp-content/uploads/2019/02/12927-Multilateral-Space-Space-Station-1.29.1998.pdf

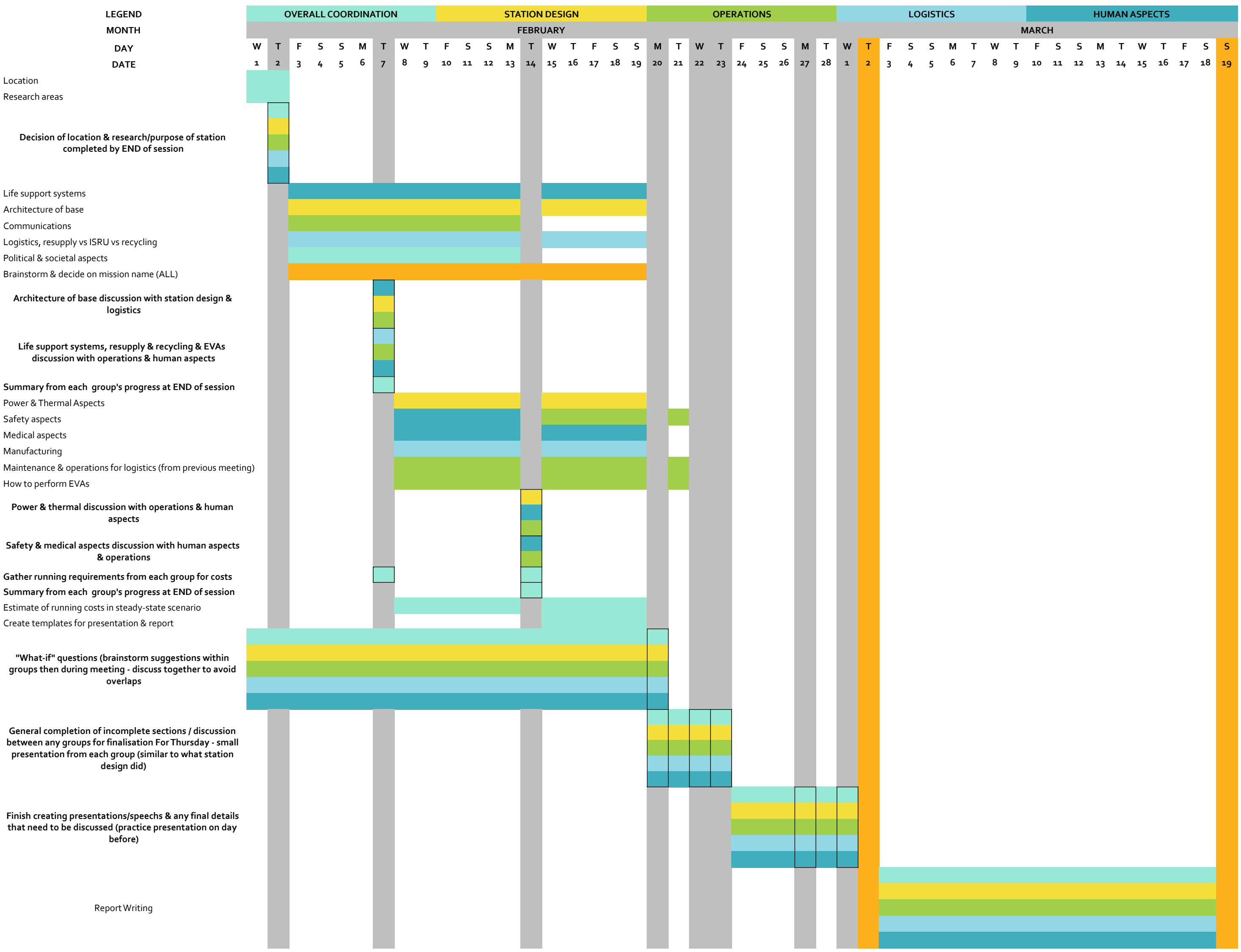
[13] Cost estimating handbook. [Online]. Available: https://www.nasa.gov/content/cost-estimating-handbook

[14] How much did the apollo program cost? [Online]. Available: https://www.planetary.org/space-policy/cost-of-apollo

[15] K. B. T. N. S. M. Anthony Drain, Jordan Boutoux, "Lunar base station design," 2023.

[16] E. Bavin. (2021, October) 5 things you should know about australia's $50 million lunar rover. [Online]. Available: https://au.finance.yahoo.com/news/5-things-to-know-about-australias-lunar-rover-003203613.html?guccounter=1&guce_referrer=aHR0cHM6Ly93d3cuZ29vZ2xlLmNvbS8&guce_referrer_sig=AQAAABX7HTUQT1BUppJFMs5Nfo2Vkz4861hil3SU_NBU3cY5k8tRuJ1CGP50wKG2I9aS6t4k7dbEIhEBYuHicxmI0yxi0lxsD2DcQY427IaDGvz0YWl6DzTdbiCOesrXizJwUdIc7z-Sk6Ycq6zwvuxxobjKnpNSZlJPMuNJ8KvzHF2v
[17] K. Houser. (2022, September) Elon musk: Starship rocket "highly likely" to fly in november. [Online]. Available: https://www.freethink.com/space/starship-rocket
[18] Cost of space launches to low earth orbit. [Online]. Available: https://ourworldindata.org/grapher/cost-space-launches-low-earth-orbit
[19] A next generation spacesuit for the artemis generation of astronauts. [Online]. Available: https://www.nasa.gov/feature/a-next-generation-spacesuit-for-the-artemis-generation-of-astronauts
[20] N. Atkinson. (2008, November) Diy iss: Big home improvement projects for space station. [Online]. Available: https://www.universetoday.com/20907/diy-iss-big-home-improvement-projects-for-space-station/
[21] Costs of an international lunar base. [Online]. Available: https://www.csis.org/analysis/costs-international-lunar-base
[22] (2015) Economic assessment and systems analysis of an evolvable lunar architecture that leverages commercial space capabilities and public-private-partnerships. [Online]. Available: https://www.researchgate.net/publication/280099331_Economic_Assessment_and_Systems_Analysis_of_an_Evolvable_Lunar_Architecture_that_Leverages_Commercial_Space_Capabilities_and_Public-Private-Partnerships
[23] Assembly of the international space station. [Online]. Available: https://en.wikipedia.org/wiki/Assembly_of_the_International_Space_Station
[24] (2022) Nasa outlines cost savings from iss transition. [Online]. Available: https://spacenews.com/nasa-outlines-cost-savings-from-iss-transition/
[25] (2018) Nasa's management and utilization of the international s pace station. [Online]. Available: https://oig.nasa.gov/docs/IG-18-021.pdf
[26] (2011) Methods for achieving dramatic reductions in space mission cost. [Online]. Available: https://s3vi.ndc.nasa.gov/ssri-kb/static/resources/Cost-Reduction-paper.pdf
[27] (2011) Nasa budget reveals even more reliance on private companies like spacex and blue origin. [Online]. Available: https://www.cnbc.com/2019/03/11/nasa-budget-more-reliance-on-private-companies-like-spacex.html
[28] (2008) Heavy ion carcinogenesis and human space exploration. Nat Rev Cancer 8, 465–472. [Online]. Available: https://doi.org/10.1038/nrc2391
[29] Nasa gateway. [Online]. Available: https://www.nasa.gov/gateway/overview
[30] Space launch schedule orbital flight test starship. [Online]. Available: https://www.spacelaunchschedule.com/launch/starship-orbital-flight-test/
[31] R. B. X. F. Matthias Rahu, Riccardo Guglielmi, "Lunar base logistics," 2023.

APPENDIX



LEGEND
OVERALL COORDINATION
STATION DESIGN
OPERATIONS
LOGISTICS
HUMAN ASPECTS
MONTH
FEBRUARY
MARCH
DAY
W T F S S M T W T F S S M T W T F S S M T W T F S S M T W T F S S M T W T F S S M T W T F S S
DATE
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
Location
Research areas
Decision of location & research/purpose of station completed by END of session
Life support systems
Architecture of base
Communications
Logistics, resupply vs ISRU vs recycling
Political & societal aspects
Brainstorm & decide on mission name (ALL)
Architecture of base discussion with station design & logistics
Life support systems, resupply & recycling & EVAs discussion with operations & human aspects
Summary from each group's progress at END of session
Power & Thermal Aspects
Safety aspects
Medical aspects
Manufacturing
Maintenance & operations for logistics (from previous meeting)
How to perform EVAs
Power & thermal discussion with operations & human aspects
Safety & medical aspects discussion with human aspects & operations
Gather running requirements from each group for costs
Summary from each group's progress at END of session
Estimate of running costs in steady-state scenario
Create templates for presentation & report
"What-if" questions (brainstorm suggestions within groups then during meeting - discuss together to avoid overlaps
General completion of incomplete sections / discussion between any groups for finalisation For Thursday - small presentation from each group (similar to what station design did)
Finish creating presentations/speechs & any final details that need to be discussed (practice presentation on day before)
Report Writing