Moon Exploration with the Deep Space Gateway Overall Coordination group

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Abstract— **The Moon exploration is often seen as a necessary step before going to Mars. The goal of this paper is to present the background, the challenges and the solutions for a conceptual study of such a mission. The current and future targets, political context and cost analysis will be discussed together with the human concerns, technical development and project management strategies.**

I. Introduction

In 1969, Apollo 11 reached the Moon and allowed Neil Armstrong to be the first human ever to walk in the middle of that gray dust. However, after the Apollo program, the governments lost interest in lunar exploration and no more trials have been made in order to conduct experiments on our natural satellite. Nevertheless, now that reaching Mars starts to be one of the main concerns for the space business, a preparatory mission to the Moon starts looking more interesting. Having this in mind, the team in object started to work on a project consisting in the design of a station, namely Deep Space Gateway (DSG), orbiting the Moon in order to lead different kind of experiments there. In such a project, 17 students have been separated in 4 different groups: the overall coordination team - whose work is presented in this paper, the Deep Space Gateway team which designed the station, the transport team working on the transport system between the station and the Moon, and finally the lunar exploration team which planned several missions that should be led on the Moon surface. Having a station around the Moon would have many benefits when studying it and preparing a trip to Mars, and this design implies a lot of teamwork that must be coordinated for the different groups in order to avoid conflict issues.

II. Mission Profile

There are two main aims in designing a space station program in the Moon neighborhood. Firstly, the science made so far on the Moon is small if compared to the unknowns that we still have about our natural satellite. Hence, a spacecraft such as the DSG opens a constant access to the lunar surface, giving the chance to numerous scientific missions to exist and to be performed relatively quickly. The second target comes from looking even beyond the Moon: given the interest that the space business is showing in manned martian missions, the necessity to enhance our preparation level for such ventures is a hot topic of these days. With a crew living in deep space, we can actually test what we know so far about this harsh environment and what has to be improved in the next future, in terms of both human impact and technology readiness.

In the light of the above, the following requirements were selected as a basement for the mission:

- Orbit - the Earth-Moon L2 South NRHO[1] (in 9:2 resonance with the lunar synodic cycle) was selected. As explained in detail in the *Deep Space Gateway Design* project report [2], an optimization study [2] shows that it is the most suitable orbit, given restrictions such as *delta-v* with respect to the Moon and the Earth, telecommunication link, thermal control, stationkeeping.
- Architecture - the mission is structured into 4 main segments: the ground segment, the DSG (space station) segment, the transport segment and the lunar segment. As shown in Figure 1,

[1]NRHO (Near Rectilinear Halo Orbit) are part of the HALO lunar orbit family, which are related to the Lagrangian Points L1 and L2. NRHO are out of the Earth-Moon plane and some of them are nearly polar with respect to the Moon[2][1].

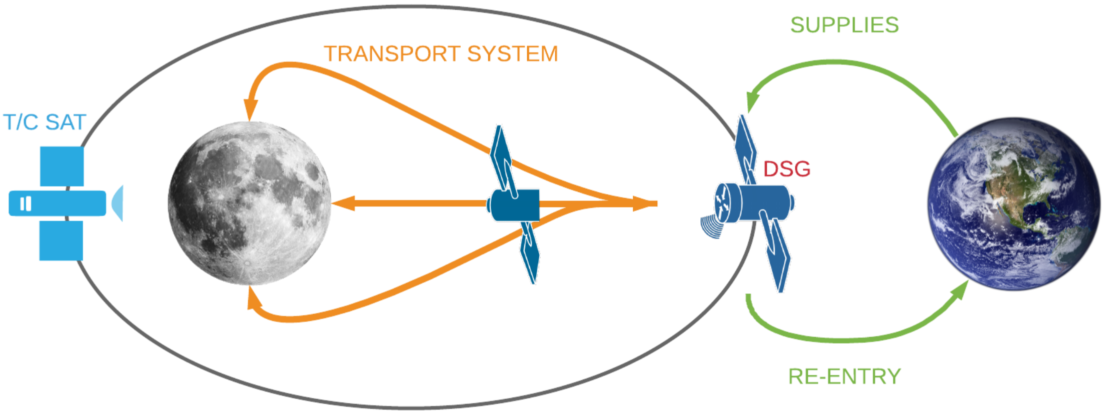

Fig. 1. Mission architecture. From left to right: telecommunication satellite (DSG segment), lunar segment, transport segment, DSG segment and ground segment.

DSG is the operations core, as it is round-trip connected with the ground segment for cargo and crew transports. From the DSG, the transport segment can move from and to several places on the Moon surface[3]. This last requirement is fundamental for the purpose of the mission, as one of the big advantages in having an orbiting space station is to establish multiple landing sites. Such landing sites form the lunar segment, i.e. a series of lunar spots in which the missions are performed.

- Link - with such a delicate scenario, a permanent good quality link is the key. Although the NRHO orbit provides a constant link with the Earth, the orbital features yield to have a several hours of eclipse in communications between some lunar locations and the DSG[3]. Considering the risks of a prolonged absence of communication between the two segments, a TC (telecommunication) satellite was included in the design. Such a vehicle is orbiting opposite to the DSG in the same orbit, so that when one is at the aposelene, the other one is at the periselene (as shown in Figure 1 and 4). This architecture is capable to cover most of the lunar surface at each time, except for a restricted area around the equator, which has some short communication gaps. The final design for the link net is shown in Figure 4 in the Appendix: DSG is the only segment communicating with all the others. During nominal operations, the ground segment is only interfaced with the DSG; the lunar segment has a link with the satellite (when the DSG is not visible) and with the station, whereas the transport system is only connected to the station. Finally, the TC satellite communicates with the station as long as this is possible (i.e. the Moon is not covering the signal).
- Lunar exploration - the program should perform 10 mission categories, capable of conducting scientific experiments, identify suitable lunar base locations for future missions, test new technologies and encourage private investment toward this exploration field. The missions have a duration of 7 days, but because the orbital period of the space station is around 6.7 days, an additional 7 days of backup equipment is needed in case of problems during the re-entry window.

III. Systems Budget

Starting from the high-level requirements listed here above, the mission analysis can move toward further details. The next step is indeed to move from the qualitative level of the former conditions to quantitative technical specifications. Based on such specification, one can realize, at an early stage, the feasibility of the mission. Usually, the three main limiting factors in a space operations are mass, power and link availability. The process of gathering detailed information about this broad parameters is called *systems budget*, divided into *mass budget*, *power budget* and *link budget*. Such a procedure is usually an iterative process, which starts from the first rough estimations and is refined step-by-step as soon as more details are available and more parts of the design are frozen. The same idea was followed in the DSG mission analysis, in which all the groups updated their systems budget regularly. The main challenge here for the Overall Coordination group was to make all the groups' requirements match together, so to have a synergistic system which is overall feasible to realize. The final results about systems budget are presented in details by each of the groups[2][3][4]. However, to understand the orders of magnitude, Table I reports the main mass and power values. Note that the link budget is instead defined by several parameters and requires a background to be properly expressed.

TABLE I
OVERALL MASS AND POWER BUDGET FOR DSG, TRANSPORT AND LUNAR SEGMENTS

	Mass [ton]	Power [kW]
DSG	75.97	152
Transport	24.06	3.01
Lunar	36.7	102.5

IV. MISSION'S PREVISIONARY SCHEDULE

When the construction of the DSG will be finished, missions will be done on the Moon and it is necessary to have a schedule for them. This part presents the different parameters considered, the previsionary schedule obtained for it and some proposition for the future utilization of the DSG after that.

A. Parameters Considered

In order to make a realistic schedule, several parameters must be considered. The first one is the frequency of the missions: according to the frequency of the resupplies the DSG would get, one mission per month can be done. Another point to consider is the length of the missions: due to the orbit chosen to reach the different sites of the moon, the astronauts need to at least stay one week on the Moon surface before coming back to the station. Another backup week must be considered as well in case there is a problem with the transport when the astronauts want to come back to the DSG, putting the classic length of a mission to two weeks. Finally, a last parameter to consider is the lunar cycles. Indeed, on the Moon, days and night switch every two weeks, and depending on the Moon site where the experiments are conducted, the dates where the missions are conducted should be during the days on the Moon. By considering these three parameters, a final schedule can be made with eleven different missions

B. Schedule

For this first schedule, the missions detailed by the lunar exploration group were considered and allowed to make a prevision until March 2026 if the missions start in January 2025. The full schedule is available in the appendix of this paper, see figure 3. However, it must be reminded that this schedule is really optimistic: it does not consider the possible technical problems that the station could encounter, or the adaptation time that a new crew would need before going for a lunar exploration. The case where a mission does not go as planned could also happen, and that would force the astronauts to come back again to do the same mission. However, since those parameters can hardly be predicted, they are not considered here.

C. DSG's Future

The final goal of this project is not to have a station operating for only two years. As explained before, some companies might have some ownership of the station and, since they would invest in this project, they would then be able to ask for the astronauts to do experiments that present an interest for them. Later, the space agencies collaborating in this project could make calls for experiments the same way the European Space Agency does with the International Space Station. Indeed, the opportunity of doing experiments on the Moon surface is unique, so it should be valuated. Commercial activities might also be considered in the future with the Moon resources, but that would need some new rules in order to regulate this new type of traffic. Finally, one great advantage of having the DSG in the future would be that experiments preparing to a trip to Mars could be done: permanent lunar bases could be built to make a first experiment of living in space. It could also be used as a Mars checkpoint, helping as a backup for communication or resupply for example. These are hints for the future utilization of the DSG, but there could be more depending of the different results that are obtained through the years.

V. Political and Societal Aspects

Political and societal aspects are overarching issues of the DSG program and are crucial for its successful development and operation. Cooperation and ownership, funding, legislation and the impact on society, are all important topics that help set the outline in which the rest of the program can be defined. Therefore these are the topics that have been chosen for investigation in this part of the report. The analysis of the DSG's needs concerning these issues are largely based on the International Space Station program.

A. *Contributing Parties*

To initiate any space program, an owner must first have sufficient funds to start development. Since funding has historically been done by national space agencies, political decisions could easily disrupt the flow of money and negatively affect the program [5]. To maintain the funds and support for the DSG program, the ownership will thus be split between several space agencies and the program will be an international cooperation, similar to the ISS program [6].

The contributing parties of the DSG are firstly the space agencies that currently manage the ISS; NASA (USA), ROSCOSMOS (Russia), CSA (Canada), ESA (Europe) and JAXA (Japan). This is because they have the relevant experience with manned long duration space programs, which the ISS program is and which the DSG program will be as well. Secondly, CNSA (China National Space Administration) and ISRO (Indian Space Research Organisation) will also be part because of their capability of manned space travel they possess now or in the near future [7][8]. Because the international cooperation includes several nations that represent many different populations, the program will hopefully contribute to a more peaceful and collaborative political climate. This spread will also help reduce costs, risks and amount of tasks for each party.

The U.S. and Russia will be the two major contributors to the program in terms of hardware, support and mission control centers (MCC-H and MCC-M), where NASA will in total contribute the most to the DSG and "run" the program, because of their previous experiences in these roles for the ISS [9]. A possible rough split of contributions could for example be; 38% NASA, 32% ROSCOSMOS, 7.5% CNSA, 7,5% ESA, 7% ISRO, 5% JAXA, 3% CSA.

Private companies will, at the start of the program, not be main contributors to the DSG because of the risk of political instability if they seek personal gain and revenue that will go into one or a few countries. They will of course still be a vital part of the program, serving several functions through the space agencies, as suppliers of goods and services or possibly "customers" that pay for research. In the program's future though, when their presence would not be as controversial, their role could possibly be elevated to be main partners, to further reduce development costs and lead times.

B. *Funding*

The funding of the DSG program will be composed of each agency's allocated funds, as well as possible financial support from private companies that are interested in expanding their businesses into space.

To promote the future commercialization of space, which will hopefully reduce the cost of space travel and enable utilization of space resources that will benefit Earth in different ways, companies will be able to provide money to the program in order to have research conducted in their area of interest (as previously stated) and as an early payment for future operational support from space agencies during corporate driven space missions.

Another source of money could be direct crowd funding from individuals. This would also serve as a good public outreach and possibly increase the knowledge and optimism towards the program, when people can see that they directly contribute to the DSG, whether they are a citizen in a participating country or not.

C. Treaties and Agreements

In 1967 the Outer Space Treaty (OST), constructed by the United Nations, was put into force and is now followed by all space faring nations that will be part of the DSG program. The OST is a good base for the DSG that serves as a groundwork of principles or rules that need to be followed, in order to maintain peaceful relations between included parties and so that all of mankind will be able to benefit of the space operations on and around the Moon, regardless of its space faring capabilities [10]. Regarding activities on the Moon, the OST also prohibits any national appropriation.

In addition to the OST, the DSG program will have a multilateral intergovernmental agreement (IGA) between all parties, that will in principle an adoption of the IGA for the ISS (which is one of ISS' purposes; to prepare all aspects for future large scale deep space missions) [11]. It will serve as a framework for governing rules, law, barter agreements, utilization of the DSG (including transportation modules) and lunar access, as well as all other aspects of operating and managing the program.

Regarding utilization, crew time of each party's astronauts and use of the DSG external elements, it will be in proportion to how much each party has contributed to the program in terms of hardware or elements and other services, as well as be decided by bilateral memoranda of understanding (MOU's) between NASA and the other parties that are included in the IGA. The MOU's describe the specific rights and obligations they have towards each other. An example of a MOU for the ISS is the one between NASA and ESA, in which for e.g. the early utilization rights of the station, before the Columbus module was installed, are arranged [12].

D. Legal Issues

Because there will be research conducted on the Moon during the program, which will use its natural resources in small amounts, the question can arise if there is need for new international laws and regulations that hinders the exploitation and destruction of the Moon and its environment. A Moon Treaty produced by the UN (entry into force 1984) already exists that heavily protects the lunar environment from material extraction, though it is not ratified by more than six nations that take part in the DSG, five members of ESA and India [13]. However, because the objectives of the program include extracting lunar material, this treaty will not be followed when the OST is adequate for the DSG's small scale operations.

The wanted commercialization of space and the expanded use of celestial bodies could provide reasons for regulations in the future since there are no such laws today [14]. Though, to legislate in preparation for the DSG program is unnecessary because the technological advancements needed that would possibly require heavy restrictions on space mining will probably not be made in the near foreseeable future of the DSG program, since there are no research missions today that prospect for future mining.

E. Impact on Society

As with the ISS, the unified main goal for the DSG program is to gain new knowledge for the betterment of humanity. All knowledge and science gained from research and operations during the program's missions will be publicly available. The possible new technologies and sciences that will arise from the program can help improve human life on Earth as well as helping humanity's future chances of colonizing the solar system, such as the Moon and Mars [15].

F. Off-nominal Scenario

An off-nominal scenario regarding the political aspect of the DSG program is if one party suddenly decides to exit the program. As stated before, the ISS has established operational procedures for this scenario in the IGA, article 17, which will in general be adopted for the DSG IGA [11].

If a party exits, it needs to transfer all assets that are vital for the continued operation of the program, e.g. if the exiting party has provided the life support system to the DSG, it needs to be handed over to another party's care according the agreements stated in their respective MOU and in the IGA. To keep the transition smooth and the operations and crew as safe as possible, there will be a minimum time frame for the exit of one year.

VI. Cost Analysis

Because the design of the Deep Space Gateway mission is such an innovative endeavour in the current space business, a cost analysis process has to be integrated from the very first stages of the design. Given the conceptual nature of the whole project, performing a procedure with highly detailed outputs does not result feasible as most of the inputs are either missing or inaccurate. Hence, the aim of the described method is rather to estimate the order of magnitude of the total cost and to depict the critical aspects of the mission economy.

A. *Cost Analysis Breakdown*

The first step is to specify which are the expense sources here taken into account. For a general space mission, one can usually divide the mission design process, i.e. the related expenses, into:

- Design - everything related to the research effort to scale up the mission phase, starting from the conceptual study and going to components and technologies definition.
- Development - all the actions performed in order to turn the design requirements into real technologies or models.
- Testing and evaluation - the activities to verify and validate the objects under development.
- Production - the actual process to produce mission hardware and software.
- Operations - the activities performed during the mission, both in the space segment and in the ground segment, to fulfill the mission requirements and to maintain the mission safety.

For the mission in question, the main cost sources are considered to be the ones listed before. However, due to the complexity of the mission architecture, such parameters are estimated for all the main mission segments (Described in section II) separately, i.e. ground segment, DSG segment, transport segment and lunar segment. The adopted strategy is therefore to calculate the sum of the costs associated to each of the segments, each of which has its own cost breakdown.

B. *Information Processing Method*

Once the cost areas of interest are set, the strategy to estimate the actual cost values for each area has to be selected. Two of the most common strategies for cost estimation, as well as for project management, investments or general information processing are the so-called *Bottom-up* and *Top-down* methods [19] [20]. Such methods can be applied to every group of information which has a certain hierarchy, in which there are high-level information, representing the broad perspective, and low-level information, depicting the smallest details contained beneath the broad terms.

1) The Bottom-up Method: Generally speaking, the *Bottom-up* method provides that, in such a group of information, the low-level information is the one which defines the high-level information. In a cost analysis context, this means that the cost of all the smallest components, operations and subsystems is determining the total cost. To do that, one should obtain or estimate the amount of money spent to produce or buy each of the components and subparts of the entire system. The final result (i.e. the final cost) is obtained by summing up all the single costs. Although this method is a rather straightforward process, it presents several drawbacks. First of all, the final value would only consider the mere production costs, i.e. the amount of money needed to buy or realize the component in object. Thus, this approach lacks the much wider economy background, which is comprising all the mission aspects listed above and not only the production costs. Therefore, such an approach would require an indirect estimation of most of the costs related to the mission, which yields to a relevant error margin, even in the order of magnitude, of the final value. Secondly, the use of this technique provides that one should know all the components used for the final design of the mission. Indeed, the components themselves define the cost estimation, hence it is vital to have a high accuracy in defining models and technologies selected. However, in a pioneering mission as the one in object, which is associated to a high-level study, listing the actual components would correspond to make a very high number of assumptions and guesses, which can really drift away from a real case. In other words, the conceptual nature of this study itself makes the *Bottom-up* technique an inadequate candidate for this purpose.

2) The Top-down Method: On the other side one can have a method in which the low-level information are a consequence of the high-level ones. This is the so-called *Top-down* method, which is often used, for example, in project management: the project manager defines outlines and deadlines for the project, whereas the teams involved have to adapt their work to fit the already defined scheme. In a cost sudy, this means that the price of all the low-level subsystems is influenced by a previous high-level definition. This second case has at least two advantages over the *Bottom-up* method. The first one is that this case is more similar to a real mission scenario, in which the mission expense has to stay below a threshold value, given by the available budget. In this case, the component selection is strictly related to the budget other than the performance. Secondly, the estimation of high-level costs can be based on previous similar cases, i.e. a statistical approach can be adopted. In case an inheritance of similar scenarios would exist, such a method would result reliable with a good level of accuracy. Moreover, the higher the number of previous cases, the higher the level of accuracy in the final result. In the light of the above, the *Top-down* approach is considered to be the most suitable for the case in object and perhaps the only one with which a reasonable cost estimation can be take.

C. The Non-operational Cost Model

To deal with the former analysis structure, the already existent *Advanced Mission Control Model (AMCM)* [21], provided by NASA, was selected. The model satisfies indeed the important features required for this cost analysis: it is a high-level model, which considers the mission general parameters rather than detailed specifications; furthermore, it is based on more than 260 space programs, which represent a very good inheritance to base the final estimation on. Among the others, the model database contains the cost for the following NASA spacecrafts: Mercury, Gemini, Apollo command module, Apollo lunar module, Skylab, Space Shuttle orbiter, Spacelab, and International Space Station. Although they span widely on the timeline, all these spacecrafts cost are relevant for the analysis of a lunar space station mission.

The model is taking into account all the expenses to produce the final system. Hence, with the AMCM one can estimate design, development, testing, evaluation and production costs. In particular, the final system cost is expressed, in millions 1999 dollars, by the relation

$$Cost = \alpha * Q^{\beta} * M^{\Xi} * \delta^{S} * \varepsilon^{1/(IOC-1900)} * B^{\phi} * \gamma^{D}$$

where the empirical parameters used are shown in Table II.

TABLE II
AMCM EMPIRICAL PARAMETERS

α	$5.65 * 10^{-4}$
β	0.5941
Ξ	0.6604
δ	80.599
ε	$3.8085 * 10^{-55}$
ϕ	−0.3553
γ	1.5691

It should be noted that the value of such parameters is based on the data related to the previous cases. Moreover, the following variables are taken into account:

- Q, *Quantity* - development and production quantities expressed in equivalence units, i.e. the total number of mockups, ground and flight models, spare parts etc. created for the mission.
- M, *Mass* - the dry mass of the system expressed in pounds.
- S, *Specification* - is related to the type of mission which is flown. The values for a crew space systems include: 2.46 for planetary landers, 2.39 for planetary, 2.27 for human reentry, 2.14 for rovers and 2.13 for human habitats.
- IOC, *Initial Operational Capability* - the system's first year of operation, specified as a year.
- B, *Block number* - is the system's block number. It represents the level of design inheritance. The value is 1 for a new design, whereas it is a certain value n if this is the n-th major modification to an existing system.
- D, *Difficulty* - qualitatively assesses the relative programmatic and technical difficulty of developing and producing the element. It may

range from -2.5 to +2.5, with an increment of 0.5. A '2.5' design corresponds to 'extremely difficult', a '-2.5' means 'extremely easy', whereas a '0.0' value represents the average difficulty.

D. Non-operational cost

The AMCM model was individually applied to DSG, transport and lunar segments, as the parameters here above differ significantly from one case to another. Regarding the ground segment, this analysis assumes that already existent facilities and systems are used, hence the non-operational cost for the ground segment is zero. Indeed, even though some development on the ground is required to run the mission, one can assume it to be not that relevant compared to the cost of the other segments.

1) DSG Segment: To have the possibility to train the astronauts on Earth, a mockup of the space station is assumed to be replicated on ground. Moreover, by summing all the engineering and test models, another unit can be added up. Hence, $Q = 3$. The dry mass was considered to be the total DSG mass minus the mass of the crew, the food and the propellant (Xenon) mass [2], which results approximately 70 tons, i.e. $154323,58 pounds$. The DSG is a space station, thus it is mainly a human habitat: $S = 2.13$. The beginning of the programme is expected to be in around 10 years: $IOC = 2025$ is chosen here. Although many differences are present, the DSG can be considered an inheritance of the ISS, both for technologies and mission similarities. Hence, $B = 2$ is assumed to be reasonable. Finally, the program is a completely innovative one: having a space station in L2 orbit is way different from other manned missions we had before. Nevertheless, the TRL is quite high for most of the technologies. Hence, $D = 2$ is considered.
With such hypotheses on the model inputs, the final non-operational cost for the DSG segment is 23519 millions of 1999 dollars, which means around 35.2 billion 2018 dollars [22], considering the US dollar inflation.

2) Transport Segment: For the transport system, the scenario is different. Firsly, note that, with transport system, the reference is only to the station-Moon line, and that the vehicles connecting the Earth with the station are included in the operational cost which will be eventually analysed. DSG is able to dock two vessels; on Earth, it is assumed to have one spare vehicle, in case a replacement is needed, plus a mockup to train the crew. This yields to $Q = 4$. The dry mass of a transport system is $M = 53034,402 pounds$ [3]. The closest category for the S parameter is *planetary lander*. However, a Moon lander is expected to have a lower difficulty level due to the lack of atmoshpere in the ascent and descent phase. At the same time, the vessel has to be reused several times round trip, which adds a certain level of complexity. Thus, $S = 2.46$ was maintained. Even in this case, we can assume to have an inheritance contribution from the Apollo program, hence $B = 2$. The difficulty level is increased with respect to the average because of the use of new technologies, such as the methane-based propulsion systems, and the lackness of mission experience in this scenario. Hence, once can assume $D = 1.5$.
With that in mind, we can calculate the transport system cost as being 46835 millions of 1999 dollars, or 70 billion 2018 dollars.

3) Lunar Segment: The lunar segment is probably the most difficult to estimate as the systems involved are often dissimilar to a space vehicle. This has to be taken into account for the validity of this result. Even for the astronaut training related to the Moon tasks, at least one mockup for each device used during the mission is needed on the ground: $Q = 2$. The mass considered here is the sum of the mass required for each mission (from 1 to 10): $M = 52884.487 pounds$. One should note that in this case the definition of dry mass is not straightforward and that the consideration of the whole systems mass definitely tends toward the worst case. For the parameter S, there is not a direct conclusion neither. However, the most similar can be probably the *planetary* case, as it represents the systems used to host humans on the surface of an extraterrestrial environment. Hence, $S = 2.39$ is chosen. Moreover, due to the lack of systems previously developed for the human lunar exploration, we can consider this as a new design: $B = 1$ and, given the mission requirements, the difficulty level cannot be less than $D = 2$.
The previous guesses yields to estimate the whole

lunar segment cost, comprising all the experiments, as 36497 millions of 1999 dollars, i.e. approximately 54.5 billion 2018 dollars.

E. Operational cost

As mentioned before, AMCM results are missing the cost needed to operate the mission. These cost includes all the expenses to keep the 4 segments working, e.g. employees salary, facilities energy cost, Earth-station transport cost and so on. Even in this case, the unknowns prevail and a high level of uncertainty on the cost estimation is risked. With this in mind, a reasonable strategy can be to take advantage of the ISS inheritance, of which we know the operational cost to be between 3 and 4 billion US$ per year [23]. ISS and DSG present several similarities in the operations: scheduled manned and cargo vehicles tranports, constant communication with the station, performance of scientifical experiments and technical tasks. However, the latter station requires more powerful transport systems, more difficult communications and very delicate operations (as missions on the Moon). This yields to consider the operational cost at least two times the ISS one.
Let us assume to estimate the operational cost for the first 5 years of the mission. Then, such an expense would be (considering the worst case of 4 billion US$):

$$2 * 4\, billion US\$ * 5\, years = 40\, billion US\$$$

F. Total cost for 5 years of mission

As shown in Table III, by summing all the non-operational and operational costs, one can get a first estimation of the total cost for a 5 years mission.

TABLE III
TOTAL COST FOR 5 YEARS OF MISSION

Non-operational cost (billion US$)	
Segment	Cost
DSG	35.2
Transport	70
Lunar	54.5
Operational cost (5 years, billion US$))	
All	40
Tot.	**199.7**

VII. HUMAN ASPECT

A. Crew Selection

The DSG will be able to shelter 6 persons maximum ; the requirements for the mission was 4 people minimum but it was deemed important to have a sufficient manpower to maintain the DSG working and send astronauts on the moon at the same time. As for their selection, the nominees will be selected among the astronauts that have already been on the ISS thus have experience in space. In the first part of the mission at least, this policy will be effective, sending person only if it's already their second flight or more. After some time it should be possible to switch to novice astronauts and send them also for their first flight.

However, whatever the experience they have, they must always have been selected following the current criteria for astronauts and they must have been trained during the required years before being sent.

B. Crew Composition

The crew composition has been decided to cover most of the required skills to run the station and also to experiment as much as possible on the moon. Thus the 6 members will be selected as following : 1 commander, 2 engineers, 1 geologist, 1 biologist, 1 doctor.

The purpose of the commander is the same as for any other space mission : lead the crew and pilot the vessels. The engineers are here to tackle any technical issue the DSG could have. Both the biologist and the geologist are meant to be dedicated to the moon mission and the scientific experiences. Finally, the choice of the medic isn't obvious but since it is the first time humans will spend a long time in space without the radiation barrier the earth provides, it would make sense to have a medic to check their health. Also he could treat minor injuries but the medical aspect of the mission will be discussed in a further part.

C. Duty and Off-duty Time on the DSG

The organization of the time on the DSG for the astronauts will be quite the same as on the ISS. Since the model has been proven and tested for so long and since the living conditions are going to be quite similar, it would be unwise not to use it.

Thus, the crew members will get 8h of sleep per night plus hours of free time everyday. The rest of the day will be scheduled in activities, some are necessary for the sustainability of the DSG, others are for science and some are to exercise to keep the body healthy for instance. Additional days off will be given to crew member every time they return from moon mission to help them recover from the harshness of the environment (of the moon and of the uncomfortable transport ship).

The missions on the DSG are meant to last a full year with rotations every 6 months to always have rookie team and veteran team at the same time. This is also the first step to analyze longer exposition to space environment and its effects on the human body. [17]

As for their free time and leisure, the DSG is equipped with basic facilities to spend time and keep the moral high. A phone with direct communication to the earth, computers, screens with movie players, sports equipment but also cards and board games. Of course cameras are available to take picture and video in space and of course a frisbee to play in micro gravity.

D. Medical Aspect

1) Problem Encountered: As said before, the crew will have a doctor on board to check on the health of every member. The DSG is equipped with a proficient medical kit meant to treat most of the diseases that doesn't require an operation. This kit will be more complete than the one of the ISS despite the smaller size of the station, such a choice is motivated by the increased distance between earth and DSG. However, for life threatening conditions, emergency evacuation may remain necessary and that is where lies the problem. [18]

One of the main problems space ever had in the human aspect is : what should we do if someone is heavily injured? On the ISS this scenario isn't much a risk since he can be carried back to earth quite fast. However, for the DSG and the missions that will happen on the moon, if the injury happen at the worst moment it could take around 5 days until they land on earth. Every astronaut has a basic medical training; they can treat small problems but they can not treat a broken leg (something that could happen during an EVA for instance). In such a scenario, probably the spacesuit will likely be pierced and before he comes back into the DSG, he will be dehydrated, partially frozen, in shock, suffering from blood loss and still has his broken leg.

That never happened before, but statistically speaking, during a manned flight to Mars which would last 900 days, that would happen and we need a solution. The DSG is the perfect place to experiment and find solution to bring the medical knowledge in space to a sufficient level to make a group of people survive any curable disease.

2) Current Researches: Some experiments have been made in during 0 gravity flight to test the possibility of a space surgery. The surgeons bumps instantly into a problem : the blood doesn't flow and just stick to surfaces like other liquids in space. The first experiment for instance was just a small incision on a rabbit body ; quite fast, the wound wasn't visible anymore because of the blood covering it. Even worse, if an artery is nicked, the pressure inside is sufficient to send the blood flying, covering your vision and contaminating everything. Then one needs to first develop efficient blood removing system to let the surgeon perform his task or else totally remove the need to cut open the patient.

Another main problem is the anesthesia; currently physician have really low data about how anesthetic drugs behave in micro gravity. Most of the test that were conducted proved that they dangerous side were worsened, forbidding them of being used in space. To perform a safe surgery, one will also need to find a suitable way to conduct anesthesia.

E. Solution Brought on the DSG and Other Conceptual Ideas

As said before, the DSG will have a permanent crew spot allocated for a doctor and the station will be equipped with a medical kit as complete as possible considering the mass and volume constraint. The doctor will always be part of the moon missions because this is where the injuries are the most likely to appear (and also the worst if not treated). Also, no EVA is planned while missions are done to avoid overlapping the risks periods. This choice is motivated by a good comprise between cost and safety of the crew.

Another solution could be to forget having any dedicated medic on board but to carry a robot surgeon operated directly on-earth. Elite surgeons could be trained on earth to operate the robot in micro gravity with the delay caused by the distance and their proficiency would probably be much higher than an astronaut. Moreover, the robot surgeon will remain unaffected by blood behavior in micro gravity since it will do laparoscopic surgeries (operation only requiring really small incision and done by inserting the tool via a tube).

The last solution currently considered is to train a dedicated crew member to the flight surgeon job but not as much as a real doctor. This means during a surgery he would perform it while being guided by an expert on earth. Being operated by someone that never did it before and is just following the directives of someone thousand of kilometers away isn't a pleasing news but it is really considered. Indeed, this would be the most cost effective way to treat injuries on board. Of course, it isn't the safest one but maybe if one consider a trip to Mars, the safest isn't always possible.

VIII. Project Management

In this part, the global structure the Overall Coordination group decided to put in place to organize the project will be briefly summarized.

A. *Meetings and communication strategy*

The events for group work were divided into group meetings and team meetings, in which the team is represented by the union of all the groups. Regarding the communication strategy, given the technical division of the work into 3 different groups (DSG, transport and lunar exploration), it has been decided to assign one member of the overall coordination to each of them, as a group responsible. The information sharing was set to be as follows: each of the technical groups can interface with its responsible; the responsible will share the information with the coordination group and vice versa; finally, there is a global coordinator which should have an outer vision on the overall project. Such a structure is summarized in Fig. 2. This structure presents two advantages: firstly, the responsible is aware of the 'bigger picture' of the project; hence, by attending the groups' meeting and keeping track of their work, it is possible for him to set everything into motion while controlling whether any choice would create a conflict with other groups' design. Secondly, with a well-defined structure it is possible to control the information flow so that the latter is always provided with a good quality and an appropriate level of details. In this way, potential misunderstanding are reduced and the flow is always passing through the overall coordination node, which is the one with the broadest view of the process.
Nevertheless, group discussions and group meetings are considered crucial for problem solving and for speeding up some processes. For this purpose, a weekly team meeting was held, in which everybody could quickly share issues and information with other team members. Finally, communication via web was always possible using the platforms described in the section VIII-C.

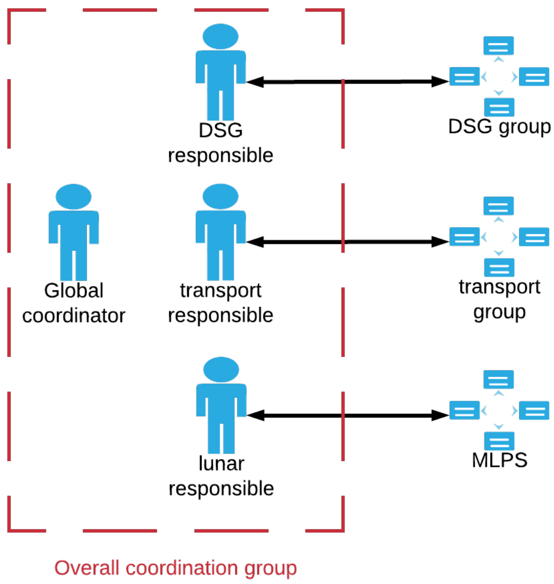

Fig. 2. The communication structure for the project management. The information are mostly shared within the overall coordination and between each group and its responsible.

B. *Gantt Schedule*

At the begining of the project, all the groups listed the tasks which they should have fulfilled to get the final expected design. Then, such tasks were organized into a Gantt chart[2] using the

[2]A Gantt chart is a timeline on which all the individual tasks are distributed, ranging between the strarting date and the deadline

website Projectplace [16]. The groups forecasted their work and the deadlines associated to every project milestone. This method is really common in project management and it is useful to keep track of the deadline and verify if the project is following the initial plan. After the verification from the overall coordination group in order to check if no key elements were left, the chart was set as the targeted timetable. A part of the Gantt schedule is shown, as an example, in the Fig. 5.

C. Online platforms and crucial documents

Project management of a large group requires coordination in the activities and common channel for communication and documentation. For this purpose, the overall coordination group selected three online platforms to operate in a shared environment:

- Google Drive - is a cloud storage system. Here, all the documents related to the project were shared, divided into group folders. One can find advantageous to have direct access to the other groups' document, in case a reference or a consultation is needed. Moreover, the fact of having shared document forces team members to write clearly, to specify all the details and in the end to produce higher quality material.
- Projectplace - is a professional Gantt schedule editor, in which all the members of the channel can have access and modify the chart (although certain fields can be blocked by the admins). Having a unique, common project schedule has the big advantage to make it objective instead of subjective.
- Slack - is a communication tool. It has two particular strengths: one can keep track of everything that it written and the communication is divided into channels. One channel per group was created, plus a channel for general communication. Each group supervisor has also access to the channel of his own group of responsibility.

Finally, it is relevant to mention that the creation of a 'shared issues' document resulted useful to accelerate the project. In such a file, each of the groups could address questions to some other groups regarding issues related to both the work environment. Collecting all these links into a sheet resulted as a good reference for further development and information sharing. That way, one could avoid to delay the critical issues until the end and end up with a last minute rush.

IX. Conclusion

The Deep Space Gateway would allow the human kind to push our knowledge about the deep space environment beyond the current limits and Mars would then be one step closer. Moreover, the lunar lands could hide great discoveries for the scientific progress. Such a program is feasible and will be surely an object of discussion again in the next years. However, some points would definitely need to be adjusted by the time it starts operating, concerning the laws or the previsionary schedule with the different experiments that would need to be done. The human aspects as well would need to be studied carefully with different experiments concerning, for example, medical treatments in a space station that is not in the Earth's orbit. A limiting factor is surely represented by the very high cost of the whole program, which requires a strong international collaboration to be dealt, not to be abandoned halfway. However, technology is going in that direction, as well as the global interest, and a possibility is present that the world will have, in the next future, the very first human habitat far away from the Earth's embrace.

APPENDIX

	2025							
Month	January	February	March	April	May	June	July	August
Moon expedition number	1	2	3	4	5	6	7	8
Dates	5 to 19	2 to 16	5 to 19	3 to 17	1 to 15	1 to 15	1 to 15	1 to 15

				2026		
September	October	November	December	January	February	March
9	10	11	12	13	14	
10 to 24	1 to 15	1 to 15	17 to 31	07 to 21	18/02 to 04/03	

Fig. 3. Previsionary schedule for the planned missions.

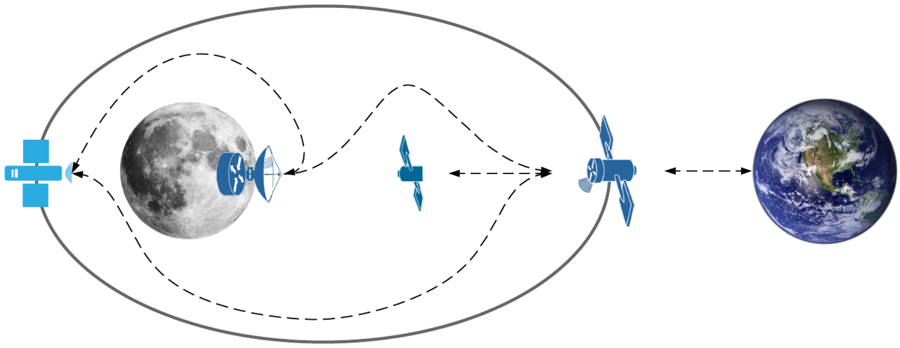

Fig. 4. Link architecture. The DSG is the only one connected with all the other segments.

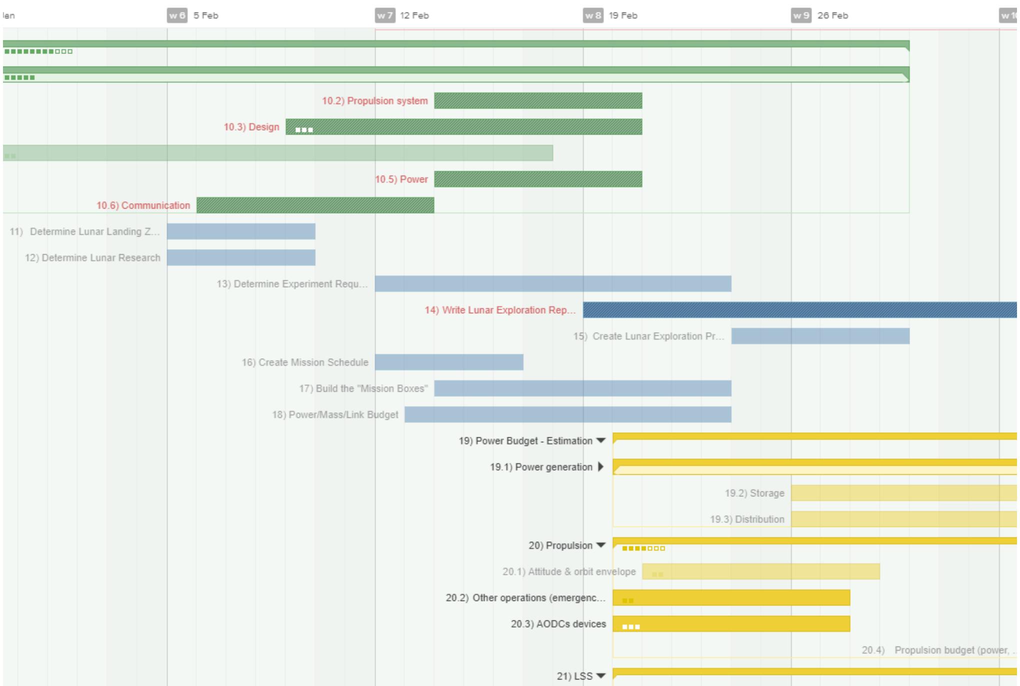

Fig. 5. A part of the Gantt chart. Different colors correspond to different group tasks.

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