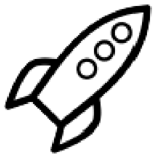
Human Spaceflight

Project Report



Administration and planning of a Lunar Base

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Contents

I Intro

This project report made by Team Blue's Group 1 – Overall Coordination, will mostly cover aspects of the mission that are not considered by the other groups of the team. A first part will describe the approach that was followed in order to decide which location on the Moon should be the one considered for the installation of a first lunar base. Then, mission profile will be addressed, describing the various means of transportations that will be needed for the completion of such a mission. A part about law concerns will be available to the reader, discussing the various problems that arise when trying to set rules for a habitat produced by international cooperation. Finally, budget concerns will be reviewed.

II Base location

The location for the lunar base was decided to be by the Shackleton crater. During the process of making such a decision, there are several aspects to consider. The aspects that have been taken into account in this project are temperature, galactic cosmic radiation (GCR), energy supply and research.

The Moon has no atmosphere, hence the surface temperature vary greatly. Along the equatorial plane the temperature vary the most, since it gets exposed to sunlight for half a month and likewise darkness for the other half. Both of the poles however have spots where there is almost constant sunlight and places in craters with constant darkness. The locations with constant sunlight could be used for the production of electricity from solar energy.

One aspect, which is hazardous to the human body and electronic equipment, is the GCR exposition. As seen in figure 1 most of the GCR are of the magnitude of GeV to TeV. Since the Moon is inside the Earth's geomagnetic field about one week every month, it benefits from some shielding from radiation during this period. This mostly provides protection of the side facing the Earth, but will provide some protection for the whole Moon. A suggestion would be that the astronauts proceed with the moonwalks during these time periods.

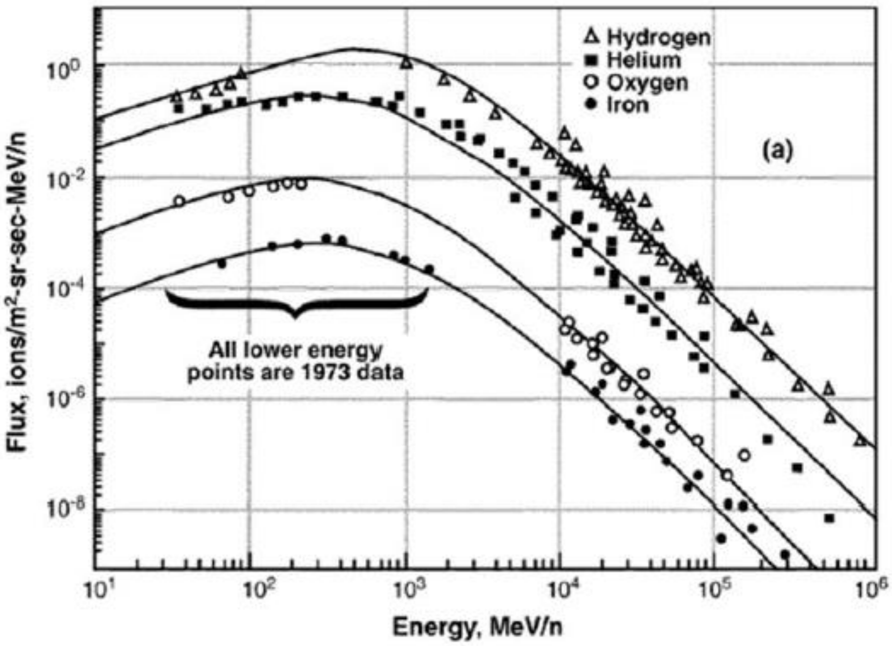

Fig. 1 : Spectrum of galactic cosmic radiation. [1]

Some observations have shown that there is a possibility to find ice on the Moon. Some craters indeed have permanent shadow, which would provide the right temperature for preserving a climate favorable for ice formation. [2]

However, in 2008 observations showed that the Shackleton crater lacks exposure of ice on its surface. In the study there was stated that the crater might still contain a low content of ice mixed with soil or that there might be ice under the surface. [3]

III Mission profile

Objective [4]

The international space station (ISS) will be utilized until 2024. It can be expected that the primary focus of human space exploration will shift to the Moon, because of both scientific objectives and prospects for human missions to Mars in the 2030s.

As boundary conditions, it is imposed that the moon base will have to be hospitable for 6 astronauts and be operational for at least 10 years. In addition, the first permanent crew is assumed to be starting their mission by the end of 2024. In order to meet this deadline, the launch vehicles available for this project have to be already available on the market or in planning stage. Orion can be assumed as an available crew transfer vehicle, while some reasonable assumptions are needed for logistics transportation and lunar landers.

- Transportation

Launch vehicles

Launch vehicles are of great importance considering the design of a moon base, which requires to transport huge masses to a distance even further than ISS in Low-Earth-Orbit (LEO). The prospect of human exploration in the post ISS era has prompted to develop heavy launch vehicles (HLVs). Table 1 shows the HLVs under operation or operational in 10 years, and their capabilities.

The selection of a launch vehicle includes various aspects, not only the cost per unit mass but also its reliability. Besides, even international politics among countries would play a major role when selecting launch vehicles. This project would certainly be an international project, so it is natural to predict that every country participating in the project would try to use their own rockets.

For the sake of simplicity of the design process, launch vehicles are classified into three groups by their capability to transport to LEO:

(i) Super Heavy Launch Vehicle (100t class) human missions (SLS)

(ii) Super Heavy Launch Vehicle (50t class) cargo/robotic missions (Falcon Heavy)

(iii) Heavy Launch Vehicle (25t class) cargo/robotic missions (Ariane, Long march and Angara etc.)

Earth - Moon transportation vehicle

For the transportation between the Earth and the Moon (E-M), either cryogenic propulsion stage (CPS) or electric propulsion stage (EPS) can be utilized. The advantage of CPS is that the duration of the flight, nominal 3-4 days, is much shorter than EPS, nominal 0.5-1 year. On the other hand, the advantage of EPS is its potential to achieve higher payload ratio. Electric propulsion is considered to be highly effective for deep space missions, thus cargo transfer to Mars, for instance, would be adequate for electric propulsion. In this moon base project, the major constraint when choosing E-M transportation vehicles is that the time for its construction is limited to only 10 years. This time frame, extremely shorter than ISS's 25 years, implies that electric propulsion would certainly show its drawback. Therefore, in this design project CPS is mainly assumed as the E-M transportation vehicle.

Lunar landers

Lunar landers would deliver various payloads. The first payloads will be small robotic probes and then the following payloads will be base construction modules, periodic cargo and eventually astronauts. Such a variety of purposes requires to develop several types of lunar landers. Their configurations are expected to differ greatly between robotic landers (RLs) and human landers (HLs), mainly because of the necessity of a life support system for HLs.

Table 2 shows an example of a lunar vehicle fleet, which derives from the landers suggested by Spudis and Lavoie [6], but the mass is scaled to meet the requirement from the launch vehicles. For this moon base design, the lunar landers in Table 2 are assumed.

⊿V Budget and Available Payloads

⊿V is a velocity increment or decrement needed to change a trajectory of a spacecraft.

If the value of ⊿V and total mass are known, one can calculate payload mass as well as propellant mass by the Tsiolkovsky's rocket equation:

$\Delta V = g0 * Isp * \ln(M0/Mf)$

Although ⊿V depends on trajectories, typical values from one orbit to another are shown in Table 3.

Since total mass in LEO is known and classified into three categories, mass to LMO can be calculated as follows:

$ML = M0 * (\exp(-\Delta V/(g * Isp)) - epsilon)/(1 - epsilon)$

Where epsilon, the structure coefficient, is equal to 0.2, which is a reasonable assumption.

The result is summarized in Table 4. Payload transportation capability per launch is now clarified.

- Phasing Schematics

Preliminary Research and Robotic Transportation

The moon base is a complex and huge system on the surface of the moon, so it cannot be built within a short period of time. First, scientific research with robotic probes needs to be conducted in order to verify the feasibility of the base construction on the selected location. Communication network as well as human habitat modules including life support systems subsequently have to be transported by larger robotic landers. After the aforementioned preparation for the arrival of astronauts, a lunar exploration craft will be launched by super heavy launch vehicle. For the permanent crew, regular freighters arrive to carry necessities for daily life as well as scientific research equipment.

The preparation with robotic landers is performed in the way shown in Figure 2. Both ERV and HL are sent in advance for the future return to the earth.

Human Transportation

Mission phasing with crew is shown in Figure 3.

The ERV that arrived in LMO during the previous phase can be utilized for the returning crew to get to the inbound trajectory and eventually to the earth. In case of an emergency event at the moon base, crew can immediately take refuge and launch the HL to the orbiting ERV. Some examples of the subsystems and essential supplies until the end of construction phase are listed in Table 5, where science instruments are not included.

IV Law

Introduction

A Moon base project will most likely be a cooperation between multiple nations, with different national laws. A major decision in creating a society on the Moon is defining which laws should apply. Today on the International Space Station (ISS) there are already many nations working together. One great difference is that on the ISS the astronauts stay no more than one year. With projects like the Moon base it is reasonable to assume a longer time-period for the astronauts in which they would have to live as a society.

One problem is that there is no defined laws for an everyday society, which all countries can agree on. For example, one question to ask is: if most of the funding is coming from the United States, should the laws of the United States rule and hence the death penalty be used?

Another question to ask is: if there is a conflict between laws from various countries, which law will be favored? The existing Space laws are a combination of national and international law, most derived from the UN laws. The international law is a set of laws which, among other subjects, treats conflicts of laws. It attends the issue with interfering laws, for example agreements and contracts that are stretched over different nations. The problem is that it assumes the fact that the affected people are on the Earth and in a country with defined national laws. Some parts of the international space laws were written 1962 and have not been updated since.

The Moon treaty discusses first and foremost the rights of how nationalities can use celestial bodies and what the limitations are. For example, it is agreed upon that countries cannot use celestial bodies for military use. The problem with the Moon treaty is that it does not contain social aspects of a community located in space. Another problem is that there are only 16 out of the world's 203 nations that have agreed upon the Moon treaty. Neither the United States nor Russia have signed the treaty.

Even though there are many rules applied for these kinds of situations, none of them are part of what is needed for a regular society to work. Instead of dealing with issues between individuals, they deal with issues between nations. The answer to the question asked before about using the death penalty if most of the funding comes from the United states, is as of right now, unfortunately yes. In a perfect world, new laws could be created on the Moon. But when it comes to several nations cooperating when creating a society, the problem with creating a set of rules collides with nations having their own private agenda.

Say for example that a Chinese man happens to kill an American on the Moon. This raises many questions; Where will he be punished and by whom? If he is sent back, he most likely will land in the ocean. Who will pick him up; the Americans or the Chinese? Assuming an American shuttle is used, it will most likely be the former. It is likely that they will refuse to give away their now prisoner, and will sentence him according to American laws, as they see fit. The point is, assuming no specific definition of which laws should apply on the Moon has been created and agreed upon by all nation using celestial bodies, no one will want to let another nation sentence their own people for a crime instead of dealing with it themselves. This means, assuming that everyone have not agreed upon the rules, that the society on the Moon is endangered to fall into anarchy.

Suggestions

In long-term a law system for Space activity and a Space embassy on the Earth would be suitable. The UN is a union of 193 nations, which would be a suitable center for handling Space jurisdiction. It is important to look into what laws are necessary to apply in the Moon society and to overview what laws are contradicting among the space nations. But as with most problems on Earth, it’s just a matter of getting everyone to agree.

Conclusion about the law system

As of now, as long as the problem of how to punish criminal individuals is not acknowledged, discussed and dealt with, by every nation planning to be a part of exploring space, a set of rules for how to treat the juridical aspects is not possible. The alternatives are limited, but there are a few. There are two alternatives that are most likely today. Either people simply get sent back to their home, and punished by their government. This means things that are legal in Russia for example, will go unpunished if done in space, even if it is illegal in every other country. This of course creates a major problem, but none that can be avoided as of now. Either that, or the one with the biggest wallet makes the decision. Assuming as always that the United States play the biggest role in creating this space station, which also means putting in up, most of the budget for the mission. This makes it their own station, and anyone who wants to take part simply has to agree upon which rules to follow, which in this case will most likely be the US law. None of these solutions are perfect, but they are the only ones which are reasonable, and therefore the only options.

V Budget

Project cost Estimation

In 2009, CSIS, a think tank, estimated a cost of $35 billion to build and operate a four-person crew lunar base [9]. This cost does not cover the development costs of the Ares V rockets and Orion crew capsules needed to get to the base. An additional cost of $7.35 billion is needed in order to keep operating the base each year. Since our base is supposed to be designed to host a six-person crew, we evaluated our budget need by increasing proportionally the budget estimation by CSIS, giving us $50 billion for building the base and $10 billion for operating it per year.

Comparison to Space agencies funds

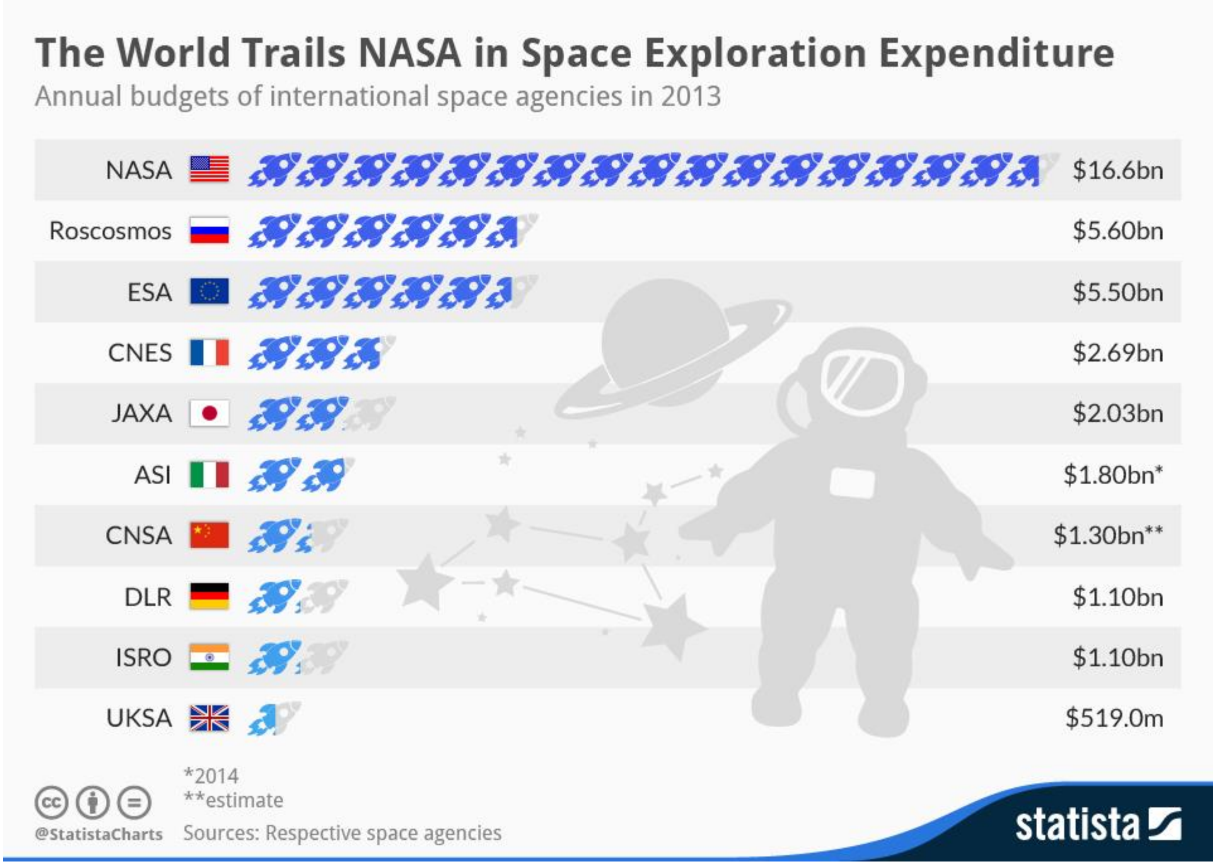

Fig. 4 [13]

As can be seen in this picture, a project similar to ours can be funded in one year if all the 7 first space agencies gather all their funds on this very project. Such a situation is highly improbable since the various space agencies need their funds to also support research and maintain the equipment that is already in use in space, on the ISS for example. Also, it would require all the agencies to work fully together, which is of course a utopic idea. However, such a comparison can be used in order to justify the fact that the idea of creating a moon base is not a fantasy but can actually be considered seriously.

Another figure also provided by reference [9] help us to further sustain our analysis: “the development cost for all but the Russian section of the International Space Station (ISS) is estimated at around $85 billion, including $35 billion for Space Shuttle missions.“ Meaning that $35 billion were used over approximately 15 years only for space shuttle missions to the ISS, most likely only funded by the USA, but also and foremost that $85 billion were used over those 15 years to build and operate the ISS. According to these figures, a moon base project seems really affordable.

Other tracks to get funding

It goes without saying that such a project will need support from Space agencies. However, we can also explore other tracks to finance the project, in order to introduce a “private company” dimension to our base. Looking at the way NASA sees the future of space travelling, using private companies such as SpaceX and Boeing to launch rockets for cheaper costs, it seems indeed unavoidable to consider this aspect.

SpaceX, for example, is approximately valued at $10 billion. Google is valued at $382 billion [10], and recently SpaceX raised $1 billion from Google and Fidelity for their Internet satellites float. Boeing has a value of $95 billion [11]. All those figures help us saying that there is more than enough money lying in private companies interested in space to build our lunar base.

Another company named Mars One has the project to send a crew to Mars. The crew is supposed to be sent there with no guaranty to ever being able to come back Earth. They estimate a (interestingly low) cost of $6 billion to send their first four people crew, and expect to be funded by setting up at reality tv show. When we know that one season of “American Idol” earned $261 M [12] in the USA only, the production of such a show seems very interesting, especially considering the fact a show about the Mars mission could potentially be aired everywhere in the world, thus earning more money thanks to the fact that it would have 1.4 billion potential viewers instead of only 219 million Americans for “American Idol” if we consider the houses equipped with a TV [13]. If the revenues are proportional to the number of viewers, and also if a season of our reality TV show is as successful as “American Idol”, it would earn about $1.7 billion.

In addition to a reality TV show, there is also the possibility to create a movie or a documentary. “Space station 3D” for example, a documentary depicting the assembly of the ISS, earned $92.2 M in the USA only [14]. “Gravity”, the 2013 movie, made revenues of about $716 M. Put together, and expecting to get similar revenues over one year, video productions could potentially cover about 1/5 of the yearly operating cost.

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VII Appendices

Vehicle	Origin	Mass to LEO [t]	Availability	Note
SLS Evolved	United States	130	2030 - after	Human mission
SLS Block 1b	United States	97.5	2021 - after	Human mission
SLS Block 1	United States	70	2018 - after	Human mission
Falcon Heavy	United States	53	2015 - after	
Delta IV Heavy	United States	28.79	Operational	
Ariane 5 ME	Europe	25.2	2018 - after	
Long March 5	China	25	No data	
Angara A5	Russia	24.5	Tested	

Table 1: List of heavy launch vehicles [5]

Name	Purpose	Total mass [kg]	Payload mass [kg]
Robotic Medium Lander (RML)	Deliver small rovers	1200	500
Robotic Heavy Lander (RHL)	Deliver robotic facilities	6000	1250
Human Lander (HL)	Deliver crew and life support system	25000	4 crew + life support system
Cargo Lander (CL)	Modified version of HL	42300	12000
Orion/Multi-Purpose Crew Vehicle (MPCV)	Human transfer from E-M	21200	4 crew + life support system

Table 2: Lunar landers and E-M transportation vehicle [6] [7]

Maneuver	Trans Lunar Injection (TLI)	Lunar Orbit Insertion (LOI)	Trans Earth Injection (TEI)
⊿V [m/s]	3150	950	1050

Table 3: Typical ⊿V values [8]

Vehicle	Origin	Official mass to TLO [t]	Estimated mass to TLO [t]	Estimated mass to LLO [t]
SLS Evolved	United States	47.5	49.0	33.7
SLS Block 1b	United States	37.8	36.7	25.2
SLS Block 1	United States	25.3	26.4	18.1
Falcon Heavy	United States	13.2	12.7	6.27
Delta IV Heavy	United States	---	10.8	7.37
Ariane 5 ME	Europe	---	9.49	6.52
Long March 5	China	---	8.76	5.79
Angara A5	Russia	---	9.18	6.29
Proton M	Russia	---	4.65	2.06
Ariane 5	Europe	---	7.53	5.03

Table 4: Comparison of payload into low lunar orbit

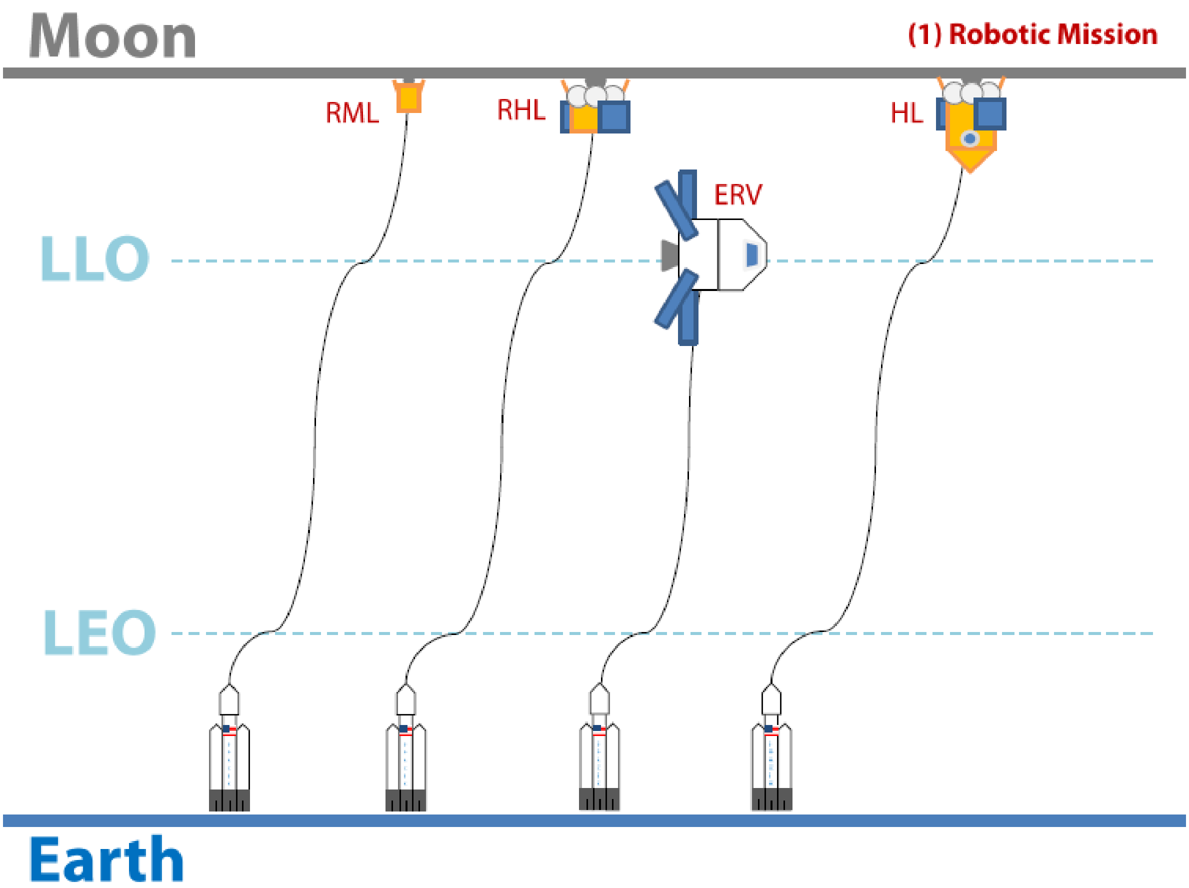

Fig. 2: Phasing schematic for robotic mission

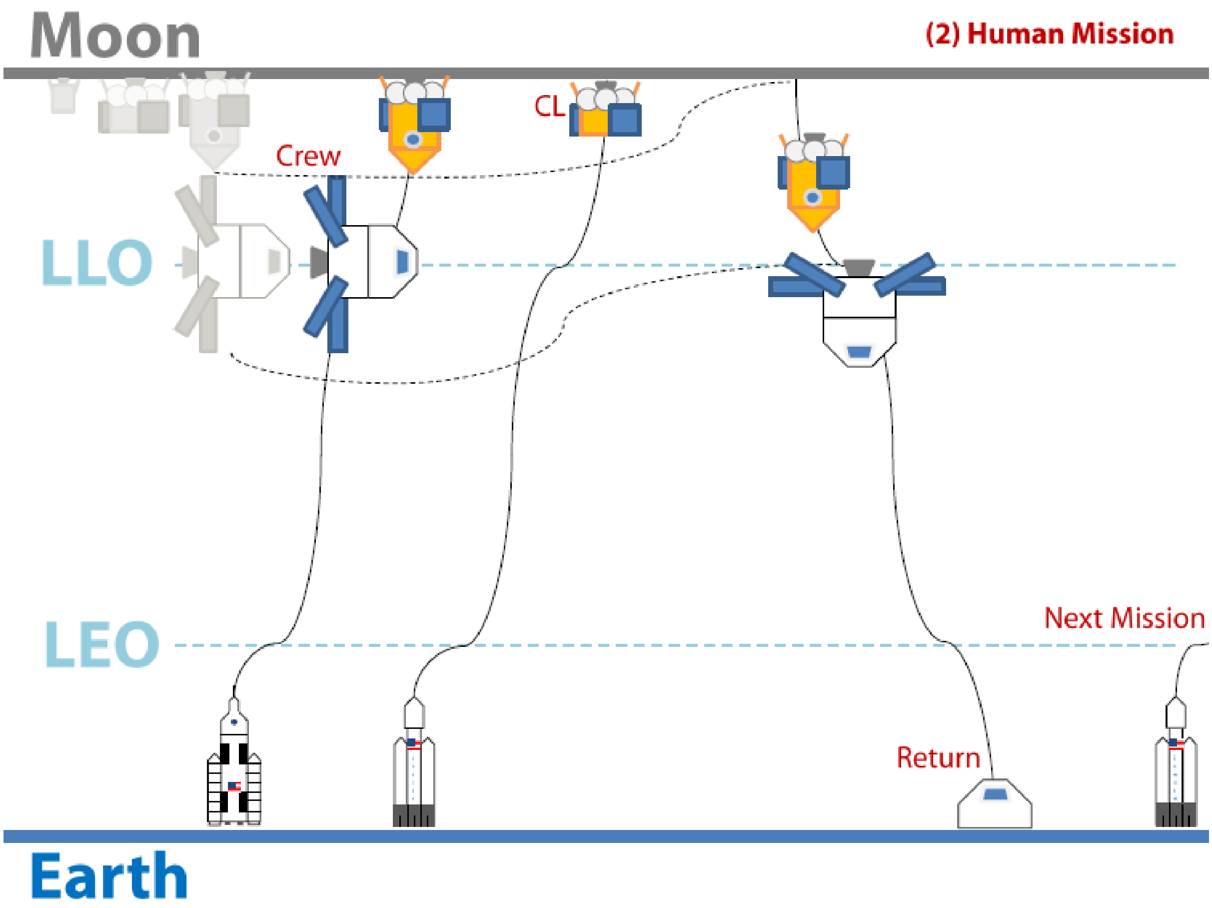

Fig. 3: Phasing schematic for human mission

The nomenclature for the Figure is:

- LLO: Low Lunar Orbit
- LEO: Low Earth Orbit
- RML: Robotic Medium Lander
- RHL: Robotic Heavy Lander
- ERV: Earth Return Vehicle
- HL: Human Lander
- CL: Cargo Lander.

Product name	Weight (kg)	Number of units	Group number	Purpose	Priority	Power (approximate	Notes
Robotic Medium Lander	1200 kg	---	1	Deliver small rovers	Very High		Payload 600 kg
Robotic Heavy Lander	6000 kg	---	1	Deliver robotic facilities	Very High		Payload 3000 kg
Human Lander	25000 kg	---	1	Deliver crew and life support system	Vital		4 crew+life support
Cargo Lander	25000kg	---	1	Modified version of HL	Vital		Payload 12500 kg
Orion Multi-Purpose Crew Vehicle	21200 kg	---	1	E-M crew transportation	Vital		4 crew+life support
Earth Communication System	30 kg	2	4	Communication with Earth	Very High	100 W	
Moon Communication System	40 kg	2	4	Moon-Moon communication	Very High	20 W when used	30 m antenna
Spacesuit	115	6	4		Very High		2kk$ per suit
Lunar Manned Rover	1000 kg	1	4	Manned traveling	Initialy low, later high		
Inflatable structure	1000-1500 kg	1	2	Moon base living structure	Very High		
3D printing rover		2	2	Print the shelter around inflatable bas	Very High		
Dry salts	3800 kg	---	2	Materials for binding liquid	Very High		
Transitory habitation module		1	2	Before relying on 3D printed shelter	Very High		
Electrolyser	200kg	1	3	Produce O2	Vital	1371	
Water for electrolys	450kg		3	Produce O2	Vital		For 3 month
Active Carbon cartridge	50 kg	4	3	Trap methane	High		Methan can also be release outside but it's part of the waste system
Sabatier's reactor	3.5kg	1	3	recycle H2 to water	Very high (double the water mass for oxyg	120 W (just launching)	
Food	4000 kg			Obvious	Vital		for 6 months (3month in case of emergency)
Water for emergency - drink, rehydrat	1300kg		3	Obvious	Vital		
Emergency Module	1200 kg	1	2	Living	Vital		
Power Module	1200 kg	3	2	Living	Vital		

Table 5: Example of mass budget