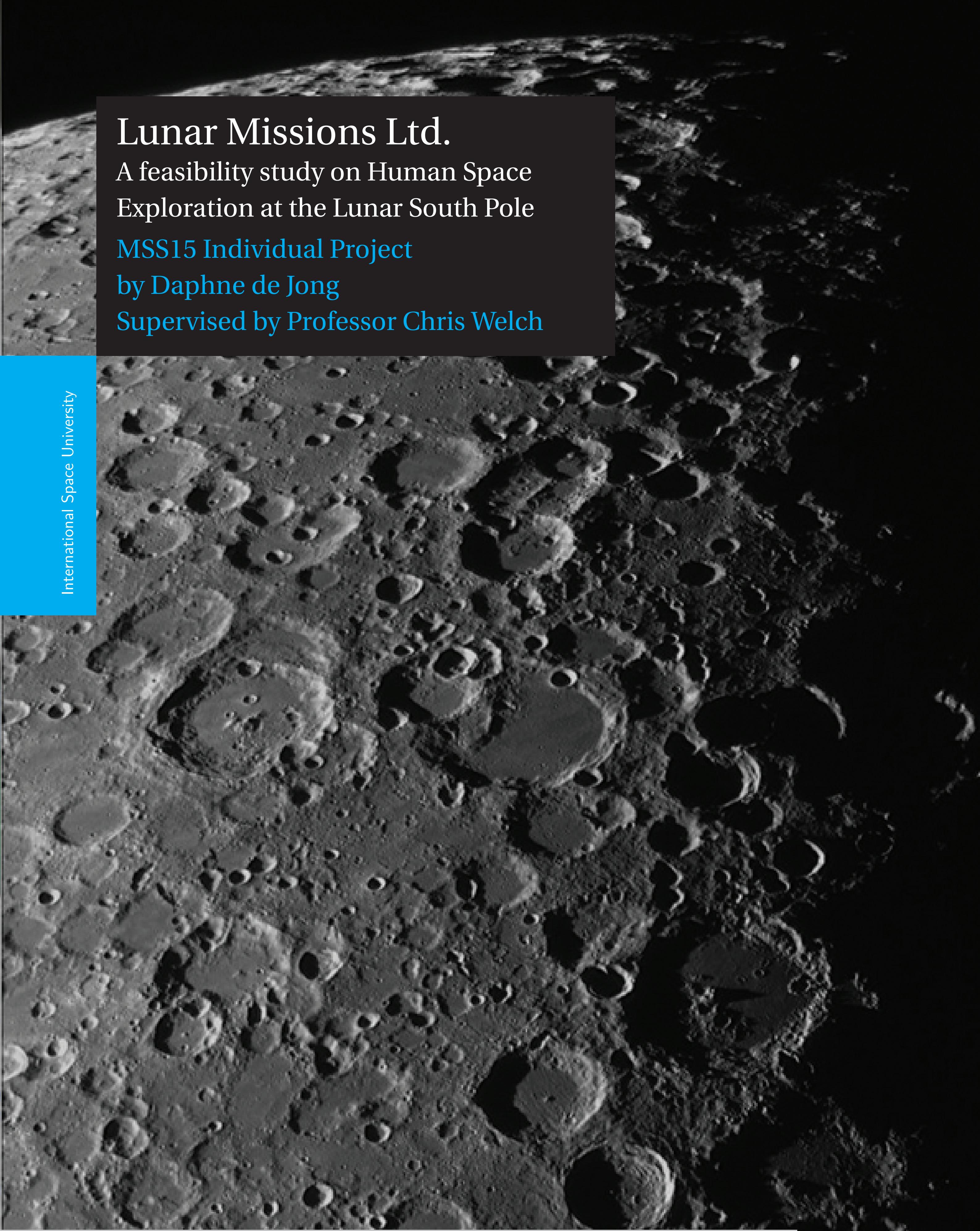

Lunar Missions Ltd.

A feasibility study on Human Space Exploration at the Lunar South Pole

MSS15 Individual Project

by Daphne de Jong

Supervised by Professor Chris Welch

International Space University

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Daphne de Jong
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April 10, 2015

In partial fulfillment of the requirements for the degree of:

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Abstract

With the modern space industry depending mostly on governmental funding, Lunar Mission One is taking a different approach. Lunar Mission One is not only a crowd funded project, it is also a science-focused mission, planning to launch by 2024. By drilling as deep as hundred meters in the Lunar South Pole, the outcome of the findings could possibly be a unique contribution to the existing understanding of the origins of the Moon and the Earth.

Where regular space missions could not be accessible for general public, the purpose is to involve people worldwide in al its phases, either by being part of the development, coming up with ideas, or backing the project on Kickstarter. Beyond Lunar Mission One, there are discussions of subsequent missions as a long-term strategy. The Lunar Mission Two will be next, providing a Lunar Sample Return, after which Lunar Mission Three will be a human mission to the Lunar South Pole.

The paper describes a possible Lunar Mission Three, which aims to create a permanent human base on the South Pole of the Moon as part of the long-term strategy, dealing with technical, political, and financial challenges, with a roadmap as a final result.

Many countries have examined the concept to land humans on the Lunar South Pole, given that this location has regular exposure to sunlight, with an eclipse duration of less than 50-70 hours, for applications including solar power, while offering a more stable temperature range, and the possibility of water ice. Regoliths at the considered locations such as the Shackleton crater and Mons Malapert are also of great interest for future In Situ Resource Utilization (ISRU) requirements. In this paper, different mission planning stages are examined, including launching methods, landing possibilities, possible human requirements, and the importance of a Lunar base.

The results of the drilling during Lunar Mission One, and a sample return during a proposed Lunar Mission Two, could provide more information on required shielding for future Lunar astronauts. In this report, different mission planning stages are examined, including launching methods, landing technologies, possible human requirements and the importance of a Lunar base.

In contrary to former researches, the report covers a multidisciplinary scope. The idea of an international cooperation on the Moon could give more people access to space, and requires strong international cooperation.

A final roadmap shows the scheduling of the mission, from the developing phase until the launch of Lunar Mission Three, following the setting of Lunar Mission One.

Key words: Lunar Mission One, Lunar Mission Three, Moon, mission planning, roadmap

Contents

NOMENCLATURE

Lunar Missions Ltd., refers to Lunar Missions as a Limited Company. The liability of member or subscribers to the company is limited with respect to what they have invested or guaranteed to the company.

Units used in the Report:

c – Centimeter, equal to 10 Millimeter
m - Meter, equal to 100 Centimeter
k – Kilometer, equal to 1000 Meter

Ga – Gigaannus, time equal to 10^9 years

a - Semi-major axis
i - Inclination
ω - Argument of Perigee
e - Eccentricity
Ω - Longitude of the ascending node
α - True anomaly

List of Acronyms

A
ARM - Asteroid Redirection Mission
B
BMDO - Ballistic Missile Defense Organization
C
CDF - Concurrent Design Facility
CLEP - Chinese Lunar Exploration Program
CNSA - China National Space Administration
D
DSE-Alpha - Deep Space Expedition Alpha
DSPSE - Deep Space Program Science Experiment
E
ECLSS - Environmental Control and Life Support System
EM-2 - Exploration Mission 2
ESA - European Space Agency
G
GCR - Galactic Cosmic Rays
I
ISRO - The Indian Space Research Organization
ISRU - In Situ Resource Utilization
ISS - International Space Station
ISU - International Space University
L
LEO - Low Earth Orbit
LLV - Lunar Landing Vehicle
LOR - Lunar Orbit Rendezvous
LRO - Lunar Reconnaissance Orbiter
LTV - Lunar Transfer Vehicle
N
NASA - National Aeronautics and Space Administration
R
RAL - Rutherford Appleton Laboratory
S
SPA - South Pole Aitken
SPE - Solar Particle Events

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1
Introduction

In a time when space agencies and commercial companies have difficulties to meet the political and public desire to go beyond Low Earth Orbit (LEO), Lunar Mission One was initiated as a lunar mission for everyone. With severe budget cuts, time pressure and changing politics, long-term dedication for such projects seem impossible these days, especially considering that humans have not set foot on the Moon since 1972 (NASA, 2011). From the first Apollo missions, the Moon has been a realistic goal for human exploration, and society has been living off the low hanging fruit for a long period of time, even though the fruit has been reduced because of, amongst others, political decisions.

Lunar Mission One is a new initiative introduced in the space community, combining public funding with an inspiring and shaping capability of exposing space science to every interested individual. It will be accessible to every person on the Earth, creating a public archive with information on history, daily life, and biodiversity we know here on this planet. People can get involved by sending data or DNA to the Moon as part of the mission. With Ian Taylor as a Chairman, Angela Lamont as Director, and David Iron as founder, Lunar Missions Ltd is a growing endeavor.

Different financing methods were introduced, even before internet crowdfunding was invented. The innovative concept includes drilling the Moon's surface up to 100 meter and storing human DNA at this depth. The three main published aims of Lunar Mission One are:

- To use pioneering robotic technology to significantly further our understanding of the origins and evolution of the Moon and the Earth, and to pave the way for future lunar missions;
- To launch a global education project to inspire a new generation of children and young people around the world to get excited about space, science, engineering, and technology;
- To create a comprehensive record of the history of humankind and the biosphere of the Earth. (Lunar Mission One, 2015)

1.1. The status of Lunar Mission One and Lunar Mission Two

Most current development on Lunar Mission One, has been focused on its online financing campaign on Kickstarter, that has been going viral all over the world.

One of the ways in which Lunar Mission One distinguishes itself from other space projects, includes the financing methods that are based on involving the public in all its phases.

There are three main stages to the fund-raising process, which are discussed further in the project as part of the chapter on financing Lunar Mission One. To give a general idea of the enthusiastic support for the project, a short overview of the fund-raising campaign will give a good indication. The first stage consisted of an international crowd-funding campaign via Kickstarter, launched at the Royal Society in the United Kingdom on November the 19th 2014. The goal was to raise approximately an amount of £600,000, equal to about $ 960,000 to fund the next development stages (Kickstarter, 2015). Clearly the project was received very positively by public, since an amount of £672,447 has finally been raised over the four week campaign, as seen in figure 1.1, introducing the second financing stage and the project management and program-planning period.

Endorsers include Stephen Hawking, Brian Cox, Dan Snow, and Stephen Fry. With support from schools, educational institutions, families, couples, and individuals, the project attracted over 7,000 backers from over 70 countries, raising over $ 1,00,000, making it a tangible and realistic project (Lunar Mission One, 2015).

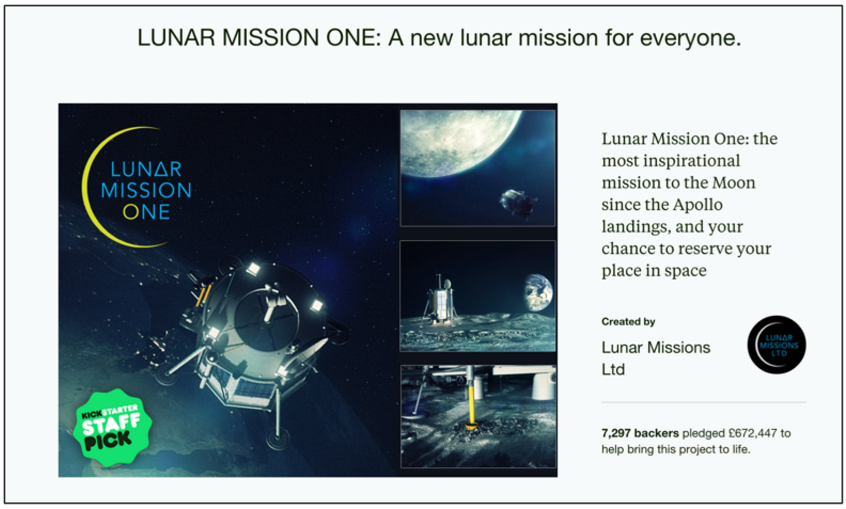

Figure 1.1: The Current Status of LM1 on Kickstarter (Kickstarter, 2015)

The main goal of the Kickstarter campaign consisted of inducing the next phase, developing and implementing plans for the next development stage. Communicating with sir David Iron, more clarity on the next stage was given. So far, the Kickstarter funds have been used for the following:

- The initial project teams are working on the planning and management of details of the first phase of the project, creating a legal joint venture of management sponsors to set up the project over the next three years. This is organized into four teams: mission procurement, science, marketing, and education, and the teams will be paid out of early revenues;
- The website has been updated on online sales, allowing more support and sharing new developments;
- A public engagement forum has been launched for worldwide discussion, as well as an online collaboration platform, the Lunar Mission Labs, where people can work together in virtual teams to contribute to the development of the project.

The next stage of the project will be announced in the beginning of July, inviting participation from around the World in the project's mission and technology planning, science requirements, supporter funding and engagement, and the piloting of the global education program.

Lunar Mission Two is pure theoretical at this point and so far not much research is conducted on this topic. The most significant about Lunar Mission Two is the aim to successfully return a drilling sample from the Moon, as part of Lunar Mission One's surface drilling project. The sample can be used for research and its purpose will not just be scientifically, but also focused on education of people all over the world.

The initiating stage of this project is still unknown and it will strongly depend on the success of Lunar Mission One, considering that both projects depend on public funding. The Chapter on funding of the Lunar missions, will provide more information on this topic.

1.2. Motivation for Lunar Mission Three

With Rutherford Appleton Laboratory (RAL) Space as its main engineering partner, Lunar Missions Ltd. has mostly be leaning on their technical findings so far. Since they made a schedule and an overview of Lunar Mission One and its operations, they calculated a launch in 2019. The published start of operations is in 2024, according to Lunar Mission One, giving the schedule space for possible extended scheduling and financing rounds (RAL Space, 2012).

Since Lunar Mission One has not been planned completely, it is difficult to assume when Lunar Mission Two will take place, following with Lunar Mission Three. Motivation for Lunar Mission Two is mainly focused on the science aspects, giving the fact that the sample return will provide data for further Lunar research to world-wide institutions.

Lunar Mission Three will be different. Besides science and engineering, especially human cooperation is a great motivation for the mission. Considering that people have been to the moon, that spacecraft have landed and taken off from the Lunar surface, the novelty will barely be found in the operational aspect itself. It will be found in the worldwide cooperation and building a solid ground for future operations. Where current space missions already lean on cooperation between space agencies and contracting companies, national politics is not always on the forefront in these projects (J.M. Logsdon, 2001).

The best example can be found with respect to current human missions, where the input on technical developments for space missions is a driver for the amount of astronauts different space-faring countries can send. Considering the not always smooth political relations between Russia and the United States, it can be found surprising how well the two nations cooperate in the space sector, with the United States mostly depended on Russia for human access to space.

Lunar Mission Three will be able to build bridges between nations that are more significant than pure a political bound, involving people from all income classes and statuses.

1.3. Project Purpose and Scope

The definition of the purpose and scope gives a good overview of the overall project. Lunar Mission Three is a very broad project and must be narrowed down in order to produce a useful end result. This is accomplished by clearly stating the mission statement, project objectives, and the constraints and assumptions.

1.3.1. Mission Statement

The project mission statement reflects the aims and objectives of the project and serves as a guideline for the final work.

"Indicate the feasibility of a public funded human Lunar Mission, or Lunar Mission Three, in sequence with Lunar Mission One and Lunar Mission Two, in a multidisciplinary way with the focus on technological aspects and human spaceflight, thus creating a financial overview, mission plan, and roadmap for the possible Lunar Mission Three."

1.3.2. Objectives

For this project, five clear objectives have been selected, which have the ability to cover the multidisciplinary approach. Those objectives will, if all achieved, lead to successful completion of the project.

The first objective is to identify the Lunar Mission Ltd. organization and research the feasibility for a third Lunar Mission as a consequence of the first two. In order to make Lunar Mission Three possible, there must be a certain public finance framework and positive public attention involved with Lunar Mission One and Lunar Mission Two. This step will also involve the cooperation with industry such as with RAL Space. This organization will pursue the technological goals set for Lunar Mission One, and will possibly be involved with the following projects.

The second objective is to understand and be more familiar with the Lunar South Pole as a location for human exploration. Known is that more solar energy could be obtained and 'Illuminated areas of the poles are thought to have surface temperatures of -53 °C (-63"F), while the permanently shadowed regions would be only a few degrees above absolute zero (perhaps around -233°C or -387°F)' (NASA, 2004). When more knowledge about the rationales to go to the south pole of the Moon will be acquired, the focus will be on other factors involved with the location such as the landing site, the soil, possible ISRU, using this location as a spaceport, and more. The result will be a clear overview of the possibilities of the chosen location.

The third objective is to look at more technological aspects of the mission, mainly different propulsion systems, human habitats, and ISRU facilities. The result will be a feasibility study for the mission on a technological point of view.

The fourth objective will consist of examine Lunar Mission Three through a multidisciplinary lens, considering social, and economical aspects. The main focus will be the economical side and a possible financial overview will be produced, taking finance methods such as crowd funding into account.

The fifth objective is to produce a roadmap with a clear overview of Lunar Mission One, Lunar Mission Two and Lunar Mission Three, and how they are aligned. Herewith the feasibility of Lunar Mission Three can be reviewed, and discovered how to make the roadmap reality.

1.3.3. Constraints and Assumptions

In order to provide context into which Lunar Mission Three could fit, some constraints and assumptions were necessary. First of all, the assumption is made in this report that Lunar Mission One will be successful, as well as Lunar Mission Two, making it possible for Lunar Mission Three tho happen. Since the launch date of Lunar Mission One and Two have not been accurately stated, the assumption will be made that Lunar Mission One will launch in 2024 and Lunar Mission Two in 2030, giving the mission enough time to be planned and developed. From this point, Lunar Mission Three will be in its starting phase.

The design of Lunar Mission Three will not be detailed, but will mainly give an overview on what is available now and what would be applicable to this future project. Furthermore, subsystems will not be discussed in detail.

Finally, non-proven technologies such as fusion engines will not be considered, but the roadmap is based on realistic and mostly tested options. Further assumptions and constraints that are applicable for specific subsections, are discussed within that part of the report.

1.4. Methodology

With the objectives clearly defined, the project has been split up in different sections.

In order to make Lunar Mission Three a success, not just a political and financial overview is required, but also many technological developments. Technological factors are included into the report, such as the landing site, Lunar base development, habitats, power supply, and more items that will be crucial factors for a Lunar mission architecture.

Finally, the rationales for a human Lunar mission will be researched and the feasibility of funding a mission such as Lunar Mission Three by public money will be discussed. Being in contact with David Iron, the conclusion was made that Lunar Mission Three will be aiming on a stay of about three months with six astronauts from all over the world, based on principles of a space program such as the International Space Station (ISS). Rationales for lunar exploration also include the satisfaction for the need to explore, new scientific findings, utilization of available resources, and much more (Eckart, 1999).

During the duration of the project, the knowledge of people around me have been used, including other International Space University (ISU) students, the project supervisor, and Lunar Mission One. Finally, traditional databases and libraries have been accessed including the ISU library, and ScienceDirect.

For the first objective, identifying the Lunar Missions Ltd. organization and research the feasibility of a third Lunar mission, the organization has been contacted, and public data is obtained in order to conclude on public involvement in scientific missions.

For the second objective, identifying the importance of the location, previously planned human Lunar missions have been researched, as well as Lunar geography, and ISRU possibilities. From the retrieved information, a combined data set has been created, indicating the important factors for the chosen location.

For the third objective, researching different technologies, used technologies for autonomous missions to the moon have been reviewed, as well as researches available on future methods.

The fourth objective, examine multidisciplinary factors, includes less technological information, and is about defining the different ways to operate Lunar Mission Three and shortly discusses international organizations and cooperation such as done for the ISS.

The fifth objective, producing a roadmap, involved combining all the information together; following the news on the funding of Lunar Mission One, and identifying its success. This required regular email contact between David Iron and myself.

1.5. Introduction to the structure of the report

This report is structured to provide a logical overview from front to back. Section one begins with an introduction to Lunar Mission One, and the current status of the project. This leads to a description of Lunar Mission Two, and the motivation behind Lunar Mission Three. The Mission Project Purpose and Scope are defined by the given Mission Statement, Objectives, and Constraints and Assumptions.

Section two describes the background of Lunar Missions Ltd. in further detail, with emphasis on the Financing Methods and Future Objectives. The main purpose is to give the reader a clear view of what has already been achieved by this organization before moving on to future human Lunar missions.

Section three explains why human Missions to the South Pole of the Moon have happened before and what the rationales were and can be for future missions. Examples of several other institutions focusing on the Lunar South Pole are given, and this overview will help the reader to understand possible gaps and recognize opportunities for Lunar Mission Three.

Section four gives more information with respect to the geology of the Lunar surface and why exactly this soil is of interest for human missions and future projects. The results will be based on past research and will provide the reader with a clear overview of the importance of the locations. ISRU is discussed here as well, leading to the advantages and disadvantages of the Lunar environment for human beings in contrary to purely scientific research.

Section five talks more about mission planning in general, mainly focused on Lunar missions. It provides information on different mission planning methods that have been applied to other missions, but it also explains why it is not possible for a single person to plan a detailed mission. This will lead to different mission planning stages, including launching, landing, human needs, and a lunar habitat.

Section six describes a financial framework of Lunar Mission Three and the current financial situation of other planned Lunar missions. This leads to different options of financing methods for Lunar Mission Three.

Section seven provides the reader with a project time management overview, without too much detail. Possible time-lines and methods are given, leading to a final roadmap for Lunar Mission three and more information on future work.

Section eight describes the Performance to Plan, giving the differences between the initial Individual Report Project Plan and how the final work deviated from this initial plan. Explanations are given and this will proved the reader with an overview on what can be learned from the way the project was set up.

The final section consists of the Conclusions and Recommendations, including a summary of results, expected challenges for Lunar Mission Three, and future recommendations. This information will clearly sketch the current situation and feasibility of Lunar Mission Three, and steps that must be undertaken to move forward.

2

Background on Lunar Missions Ltd.

This section will provide an overview of Lunar Missions Ltd., and how they are set up, expending from the introduction section.

Lunar Mission One will send an unmanned robotic landing module to the South Pole of the Moon, using pioneering drilling technologies down to a depth between 20 and 100 meters. Lunar rock will be reached that dates up to 4,5 billion years, something that has not been done before. The main drive is to go back to the beginning; to the ancient relationship the Earth shares with the Moon and effects of asteroid bombardment. One of the goals is scientific understanding of the solar system, and obtaining more information on how the Moon shaped and how conditions on Earth depend on this (Lunar Mission One, 2015).

Several Theories have been proposed for the formation of the Moon, which will be further explained in section four. The most popular theory, the so-called 'Ejected Ring Theory', believes that the Moon formed because of the impact with a body with the size of Mars, causing a large volume of material to be ejected and shape the Moon in the Earth's orbit (NASA, 2001).

500 million years after the formation of the Moon, the inner Solar System is believed to have been victim of heavy asteroid bombardment. With the high amount of geological changes on the Earth, it is difficult to find evidence, but since the Moon generally does not experience such significant changes, it could hold valuable information about the affects of the asteroid impacts.

Lunar Mission One could shed further light on whether the Moon shares its origins with the Earth and would allow more understanding about the Moon's geological composition. This would be important information for all people worldwide.

Besides learning more about the Moon, the goal is to learn more about the Earth and its history. The initiative to work on a Public Archive, is innovative and challenging on this scale. By bringing together academics, schools, and the general public from all over the world, Lunar Mission One will provide the aids to create an archive which will be publically assembled. This digital digital record of Life on Earth, with a reflection on human history and civilization, and a scientific description of a biosphere with a database of species, will be free to access (Lunar Mission One, 2015). The record will be accessible to all, which can only be made possible by a project this size. The first edition of this public archive will be part of Lunar Mission One, burying it deep below the Moon's surface in a drilling hole, making it the 21st Century equivalent of a time capsule.

Along the public archive, the so-called time capsule will contain millions of individual 'digital memory boxes' that can be bought, consisting of personal digital data. Another option is to store the DNA code in a physical space, via the submission of a strand of hair.

During the next four to five years, the project will be further developed and an online portal for people will be created to start uploading information into their digital memory boxes.

When the campaign on the crowdfunding Kickstarter website was launched in 2014, popularity was obvious and over $ 1,000,000 was raised for further development of the project, making this a Lunar mission for everyone (Kickstarter, 2015).

The Lunar Mission Club has been launched for people who pledged £30 and above, giving members the opportunity to discuss with the organization, and investigate key decisions about the mission during its development phase. Once established, it will still be possible for people to back up the project.

Involvement from schools is also a possibility, as part of the Education Programme's pilot programme. Over the next ten years opportunities will arise for students to become involved and learn more about all the different aspects.

The governance of the Lunar Mission One project is overseen by the Lunar Missions Trust, a non-profit organization. Any surplus revenues from Lunar Mission One will be placed in the Trust, to support further space exploration and fund future space projects. The Trust consists of three different persons; Sir Graeme Davies as the Chairman of Lunar Missions Trust, David Iron as the Founder of Lunar Mission One and Lunar Missions Trust, and Professor Monica Grady as the Trustee of Lunar Missions Trust. Their vision is to ensure a meaningful, substantial and inclusive global legacy gained from the success of Lunar Mission One (Lunar Mission One, 2015).

Lunar Mission One has a wide variety of Partners and Advisers, ranking from Universities to commercial companies with plentiful experience. Endorsers include Professor Brian Cox, Professor Stephen Hawking, Dame Julia Higgins, Lord Martin Rees, Dr. Maggie Aderin-Pocock, Jim Al-Khalili, Ian Taylor, Professor John Zarnecki, Adam Afriyie, Iain Gilmour, and many others from all over the world, promoting Lunar Mission One and work on its success.

2.1. Technology and Design of Lunar Mission One

This section is meant to give the reader a general overview of the Technology and Design of Lunar Mission One. The technical design of the mission has been taken over by RAL Space, located in the United Kingdom. They have performed studies in the so-called Concurrent Design Facility (CDF), which is a facility in which all the sub teams and leaders are seated, including the Systems Engineer, Drill, Payload, Robotics, Mission and Propulsion, Guidance Navigation and Control (GNC), Communications, Power, Thermal, Structures and Configurations, and Cost, Risk and Schedule specialists. Using this facility is an efficient way of planning a mission, with all the applicable people in one room. The method will be further explained in section five, in which mission planning is a central topic. RAL Space was given the assignment to include the following segments:

- A landing vehicle with a number of payload elements, specifically a lunar (regolith) science instrument suite, a set of archive capsules to be delivered to the borehole to form the archive;
- A propulsion system to enable a soft landing;
- A navigation system to allow the lander to target a 100m - 100m target on the lunar south pole from a trans-Lunar injection starting point. The targeted region is likely to be a ridge on the edge of a crater offering a majority of days of sunlight over the course of a lunar year; the precise area will depend on further analyses of existing data;
- A communications system to provide real-time descent information to aid precision targeting, transmit sufficient payload data back to Earth to complete the mission objectives;
- Suitable power generation, energy storage, thermal control, structural interface and command / data handling subsystems to perform mission functions for as long as possible;
- The potential to survive a lunar night as a desirable but not mission-critical capability;

- A launch vehicle built in the United States, in order to facilitate international collaboration. The launcher upper stage required to inject the lander into a lunar transfer orbit has not been examined in detail but has been assumed to be available and matched to the mission delta-V and the delivery mass to Low Earth Orbit;

- The following payloads: (a) The Ark of Humanity archive payload, consisting of capsules and storage / dispensing cassette, plus a robotic deep drill; (b) A multiple degree of freedom robotic arm; and (c) a suite of scientific instruments targeted at measuring regolith and surface dust properties;

- An ability to handle and store 1000 capsules each 5cm in length and 2.7cm diameter, to be deposited in a borehole a minimum of 100m deep for the Ark payload (RAL Space, 2012).

The design philosophy was aimed at deriving the best value for money mission, and to to achieve a balance between cost, risk and capability. Six different CDF sessions have been conducted and the outcome can be seen in figure 2.1 below and the different steps in the mission are explained under the figure.

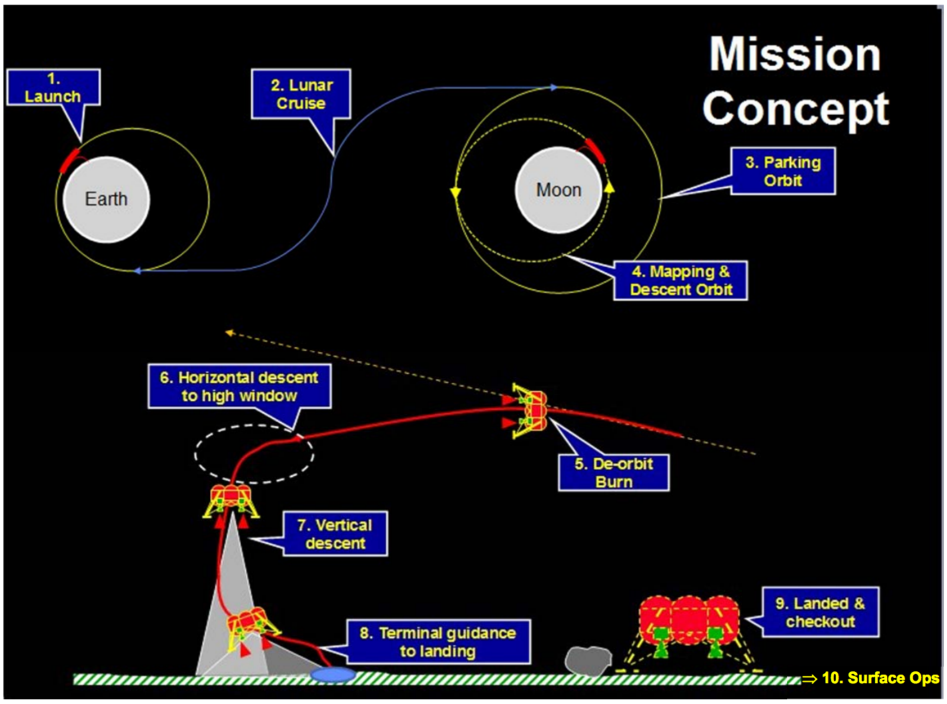

Figure 2.1: Mission Concept Lunar Mission One (RAL Space, 2012)

- Earth departure and Lunar cruise plus any mid-course corrections. These are well-understood maneuvers with low delta-V uncertainty and well-defined start and end points, so do not greatly drive mission risk;

- Entry into a low circular 100km Lunar ‘parking orbit’. This orbit should be stable and its parameters accurately measurable over at least a month;

- If required, adjustment of this orbit into an elliptical 100km × 10km ‘mapping and descent’ orbit, aiming to use the lander camera system to verify target suitability at high (<0,5m) resolution. This orbit is not stable so a parking orbit must be returned to after imaging, to allow time for processing and planning descent to the lunar surface;

- Readjustment to the parking orbit for processing and identification of the optimum landing site. This needs to be done a month in advance of landing so that lighting conditions are approximately the same for mapping and landing, within the limits of the optical navigation system;

- Return to the descent orbit, and initiation of a de-orbit or propulsion deceleration maneuver. This maneuver is designed to place the BA lander into a defined region of space above the lunar surface with velocity in a precisely calculated range. The lander thrust:weight T:W is critical during this maneuver since it defines the trajectory velocity losses and the required system delta-V.

- This position and velocity 'high window' targeted can range between the extremes of a maximum velocity at minimum altitude (maximum T:W weight required, maximum translation) and minimum velocity at maximum altitude (minimum T:W, vertical descent). The lander reorients at this point to a vertical descent trajectory and maintains the continuous thrust begun at the start of de-orbit. Besides controlling vehicle attitude (allowing lateral movement of the vehicle), the RCS provides control of the descent rate, targeting a main engine cutoff at 10m altitude with zero vertical velocity.

- The target zone of 100 - 100 meters has been selected by mission planners on Earth and the lander will operate automatically to reach main engine cutoff. However the limitations of the camera mapping before landing mean that last minute hazard avoidance will be needed. Hazard avoidance is autonomous with an option for a teleoperator intervention from Earth to steer the lander away from apparent obstacles.

- Final landing will utilize a crushable landing gear structure to absorb the energy of the drop from main engine cutoff point and any residual vertical velocity. Residual lateral velocity will need to be minimized such that the final velocity vector remains inside the landing gear footprint, to minimize the risk of the lander overturning. A maximum landing site slope of 15° is recommended (RAL Space, 2012).

Considering the mission design, a schedule has been provided for Lunar Mission One with target dates specific from RAL Space. Those dates are earlier than the ones planned for by Lunar Missions Ltd., giving enough space before the actual scheduled launch frame in 2024. In figure 2.2 below, the schedule produced by RAL Space can be seen. Emphasis is put on the right side of the figure, the different Phases will be explained later in Section Five on Mission Design.

Phase	Activity	Period (months)	Nominal END date
A/B	Systems design & preliminary technology risk reduction. Competitive design studies by contractors. Completed at PDR.	18	Jan 2015
C	Detailed subsystems design, further technology risk reduction. Completed at CDR.	30-36	Jun-Dec 2017
D1	Subsystem (module) manufacturing and testing. Completed at MRR. *NOTE runs concurrently with Phase C.*	*See above*	
D2	Spacecraft assembly, integration, test (AIV) & delivery; Launch assembly & preparation. Completed at FRR.	12	2018-2019
E	Launch & Space Operations. Transport from Earth to Moon	1	2019
F1	Primary mission Lunar Operations : Drilling, science & archiving	~6-9	End 2019
F2	Extended operations period: lunar surface science	24+	End 2021
		TOTAL: 6-7 yrs + F2 extended operations phase	

Figure 2.2: Mission Schedule RAL space (RAL Space, 2012)

A significant technological challenge of Lunar Mission One is the drilling process. There are many constraints to drilling beneath the surface of the Moon, including a low mass drill, the absence of cooling liquid, the extreme cold, the remoteness of the location, and the limited power and forced periods of inactivity during the dark winter.

The drilling operations will use the latest wire line drilling technology, using an anchor to the side of the borehole to lower the drill system inside the hole. The drill will be configured to extract 2,5cm diameter core sample with 15 cm in length, which will be analyzed on the Lunar surface. After the hole has been finished, the drill assembly will deliver the time capsule in the borehole, which will then be plugged (Lunar Mission One, 2015).

2.2. Financial Situation of Lunar Mission One

This section will describe the current financial situation of Lunar Mission One. Most current development on Lunar Mission One, has been focused on its online financing campaign on Kickstarter, that has been going viral all over the world.

Kickstarter is the biggest global crowdfunding platform based in the United States. People who back Kickstarter projects can be offered a certain reward or experience. Crowdfunding is a method of funding a project by raising money from a large amount of people, usually via the Internet (Kickstarter, 2015).

One of the ways in which Lunar Mission One distinguishes itself from other space projects, includes the financing methods that are based on involving the public in all its phases.

There are three main stages to the fundraising process. The first stage consisted of an international crowdfunding campaign via Kickstarter, launched at the Royal Society on November the 19th 2014. As mentioned in the introduction, over $ 1,000,000 has been raised with this campaign.

A wide range of incentives can be pledged to secure by public, although the main focus will be to reserve a ‘digital memory box’ that will eventually be included by Lunar Mission One, giving its buyer the opportunity to store information and DNA under the Lunar surface. The memory box can be filled with personal information including messages, photos, audio, video, or a string of hair.

Packages can be priced in different ranges, either a few dollars, over $ 10 for information packages, or over $ 100 for the combination of digital information and a string of hair. Finally, the so-called prestige package is available for $ 1,000. The possibility to reserve a space in the private archive will exist for the next four years and will be the second phase of the financing procedure. Membership of the new Supporters Club allows people to stay involved and be part of the thinktank for future developments.

The third finance phase consists of a global sales and marketing campaign, which will further spread the word of Lunar Mission One and make information accessible for general public all around the world.

Based on previous performed market research in the United Kingdom and the United States, a strong interest in the mission and the digital memory boxes has been demonstrated, predicting that about 15 percent of the global population will be able to afford the product and 1 percent of this group will actually purchase a digital memory box, with the mid-point projected revenue of £3 billion, $ 4,7 billion (Lunar Mission One, 2015).

2.3. Future Objectives for Lunar Mission One

Since the first step of Lunar Mission One is completed, the crowdfunding via Kickstarter, the follow up decisions have to be made and a clear plan has already been presented. Those decisions have been communicated with sir David Iron and presented in this report.

Three years has been anticipated on to set up the main contract for the space mission itself, since Lunar Mission One is now in discussions with a number of key industrial companies, and will be inviting them to form into consortiums that can bid for the work. These consortiums will be international in nature, and cover all the technologies that the mission requires, such as the drilling equipment, spacecraft, landing avionics and navigation, and of course the rocket to launch it all into space.

Over the three-year period, the Science Team will plan and develop their detailed requirements and instrument payload, including the progress of the science of the archive. International collaboration is the main focus, together with universities and institutions all over the world, between different nations, which reflects the collaboration within Lunar Mission One itself.

Considering that the main sales and marketing campaign is only due in a few years, it will be of great importance to spend early revenues critically, and help to pay for the project as it is set up to demonstrate Lunar Mission One's business case. A global marketing organization will be selected within the next two years. The global education program will be prepared over the next three years, with pilot schools around the World testing out ideas, having the opportunity to make history and create a lasting global legacy.

2.4. Lunar Mission Two

As mentioned in the Introduction, Lunar Mission Two is mainly a theoretical plan and is strongly dependent of the success of Lunar Mission One and Lunar Mission Two. The mission will consist of a sample return mission, using equipment that has already put in place by Lunar Mission One and it could even consist of returning the ground samples that have already been taken back to Earth. This mission will however give a clearer overview of the findings during Lunar Mission Two and can be critical for Lunar Mission Three. The Lunar South Pole is a new terrain and the more information obtained before sending humans, the better. At this point Lunar Mission Two is mostly an idea that needs further thought and time, but is a serious initiative.

3

Missions to the South Pole of the Moon

The total of attempts of missions to reach either the Moon's orbit or its surface is 123, of which 55 were successful. Failures occurred mostly because of a launching vehicle, a change of budget, a wrong trajectory, or no data return (The planetary Society, 2014).

The Lunar South Pole is of special interest for many scientists considering that sunlight reaches the surface for long periods of time, while it does not reach the bottom of the craters, as seen at the North Pole of the Moon. More information on the early Solar System can be provided by drilling down the surface, as planned by Lunar Mission One. A significant amount of research has already been done on the Lunar South Pole, spacecraft from all over the world have explored this region, including the Lunar Orbiter, Clementine, Lunar Reconnaissance Orbiter, Lunar Prospector, Kaguya, and Chandrayaan (The planetary Society, 2014). Missions such as NASA's Apollo and Surveyor, landed near the equator, no further than 40 degrees latitude. The terrain at the South Pole region is less flat and more difficult to provide access to (ESA, 2015).

The United States initiated the The Lunar Orbiter Program, managed by NASA Langley Research Center, consisted of five separate launched unmanned Lunar orbiter missions, that were performed between 1966 and 1967 (Lunar Planetary Institute, 2014). The initial intention was to help selecting Apollo landing sites by mapping the surface of the Moon. Wit a total cost of about $200 million, it was good that all the missions were successful. 99 Percent of the Moon has been mapped, by taking photographs with a resolution of 60 meters or better (NASA, 2010).

Clementine, or 'Deep Space Program Science Experiment' (DSPSE), was a project of both the Ballistic Missile Defense Organization (BMDO), and NASA. The main objective of the mission was not only to observe the moon and near-Earth asteroid 1620 Geographos, but also to test spacecraft components under extended exposure to the space environment. The observations, made in the visible wavelengths, as well as in ultraviolet and infrared, obtained imaging of the entire Lunar surface and assessments with respect to the surface mineralogy were made (NASA, 1997). One of the images taken from the South Pole by Clementine, can be seen in figure 3.1.

The Lunar Reconnaissance Orbiter (LRO) is a NASA spacecraft orbiting the Moon in order to map the Polar Regions. The orbit is 30 by 180 kilometers and it serves as a precursor mission to future Lunar human missions. Potential resources, landing sites and the environment are key factors for this mission. The total cost is about $ 583 (NASA, 2009).

The Lunar Prospector was a 19 month during mission, designed to investigate the lower Polar orbit of the Moon and to map the composition of the surface, specifically looking for polar ice, which it succeeded to find. The final result was a detailed map of the surface composition of the Moon.

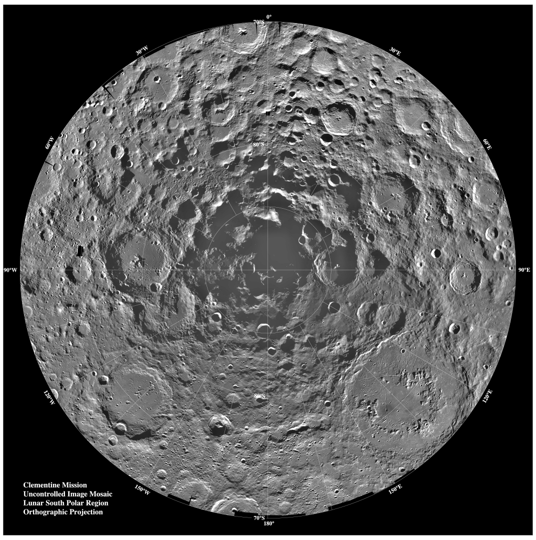

Figure 3.1: Image of the Lunar South Pole by Clementine (NASA, 2015)

Chandrayaan-1 was launched as India's first Lunar spacecraft. The Indian Space Research Organization (ISRO) launched the spacecraft in 2008. Its purpose was to map the chemical components and three-dimensional topography of the Moon. In 2009 the probe impacted the Shackleton crater at the South Pole. During this procedure sub-surface soil got ejected, which can by further analyzed for Lunar ice.

Even though Lunar sample return missions have been conducted, they were not at the exact Lunar South Pole. After the Soviet failed two attempts to return Lunar soil by the Luna missions in 1969, the manned Apollo 11 by the United States, returned about 22 kilograms of Lunar surface material. The following Apollo missions returned even more weight, giving scientists on Earth a chance to further analyze this data. The first robotic missions to return Lunar soil, were the Soviet missions Luna 16, and Luna 20. China is planning a sample return mission around 2017, which will be a significant moment considering that over the last 40 years, no Lunar sample return missions have been conducted (The planetary Society, 2014).

3.1. Passed Human Lunar Missions

This section will describe past Human Lunar missions in general, giving the reader an overview to better understand Lunar Mission Three in the following sections.

From 21 December 1968, when the first manned Orbiter mission successfully operated, until 7 December 1972, when a manned Orbiter, lander, and rover mission finished, humans entered the Lunar environment (NASA, 2007). Now, 42 years later, there is still no permanent human presence on the Moon. In this report, there will not be a focus on the political reasoning behind this lack of human Lunar missions, but simply an overview leading to Lunar Mission Three. This could be the start of something only speculations exist of. Most information about the Apollo missions has been made available by NASA, which was helpful for this report.

The Apollo missions provided surface samples and photographs of the Moon from separate locations. The geography of the landing site was of great importance, considering that they have been chosen to be on different places. This has been done in order to shape a picture as complete as possible of the Lunar surface, ranking from young to old soil, from impact crater to regular Lunar surface. Although the Apollo missions provided significant information, they were not mainly focused on the South Pole of the Moon. The soil closer to the equator turned out to be more smooth and brought less implications for the crews landings. Figure 3.2 shows various landing sites of the Apollo missions (ESA, 2015).

The first human Lunar mission was NASA's Apollo 8, launched on December 21, 1968. For the first time the

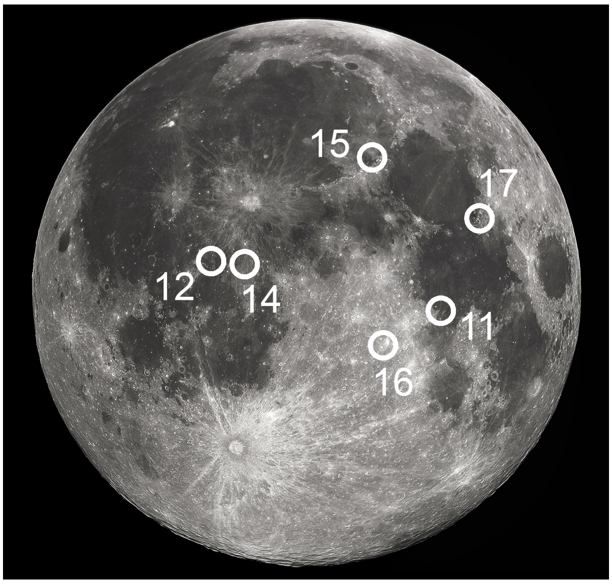

Figure 3.2: Several Landing Sites of the Apollo Missions (NASA 2014 and own work)

Earth orbit was left in order to reach the Moon's orbit and the crew safely returned to Earth. The astronauts were the first ones to see the far side of the moon, bringing back priceless memories. The Apollo 8 crew traveled three days to the Moon, followed by ten orbits within twenty hours (NASA, 2007).

Apollo 10 was the second manned Lunar mission, performed by NASA as well. The purpose of the mission was to practice for the first Moon landing by testing the procedures and systems. The distance from the Lunar surface was within 15,6 kilometers, which was the height at which the powered descent of the lander mission would normally begin. The spacecraft launched on May 18, 1969 and its duration was eight days.

Apollo 11 was the world-famous spaceflight, landing the first crew on the Moon, consisting of Neil Armstrong, Buzz Aldrin, piloted by Michael Collins. In the 2,5 hour walk on the Lunar surface, both Neil Armstrong and Buzz Aldrin collected 21,5 kilograms of lunar soil that was returned to Earth (NASA, 2007). The flight duration was just over eight days. (ESA, 1992)

Apollo 12 was the second mission that successfully landed on the Moon. The concept was similar, two crewmembers spend one day and seven hours on the Lunar surface while the pilot remained in Lunar orbit. The total flight duration was over ten days (NASA, 2007).

Even though Apollo 13 was meant to reach the Lunar surface, the crew never made it. The launch was on the 11th of april in 1970. Soon became clear that landing on the Moon's surface was not a possibility, after an oxygen tank exploded two days after the launch. The crew landed safely back on Earth on the 17th of April, despite the difficulties during the flight, including the loss of cabin heat, the shortage of water, and other problems caused by a reduction of power. The final mission duration was just under six days (David et al, 2013).

Apollo 14 was the third mission to land on the Moon. During two Extra Vehicular Activities (EVA's), a total of 42 kilograms of Moon rocks have been collected by the crewmembers and several experiments have been performed, under which seismic studies. The total mission duration was over nine days (NASA, 2007.

Apollo 15 was the first mission with the purpose to stay longer at the Moon's surface, giving more time for science than during previous missions. The Lunar Rover made its first ride on the Moon, making this a significant Lunar mission. The distance from the Lunar Module was bigger because of the Lunar Rover, which made the collection of about 77 kilograms of Lunar material very interesting for scientists. The Pilot that orbited the Moon in the meanwhile took a great collection pictures using a panoramic camera, a laser altimeter, and a gamma-ray spectrometer. The total flight duration was twelve days and seven hours (David et al, 2013).

Apollo 16 was the first mission during which the crew managed to land in the Lunar highlands. The crew spend just under three days on the surface of the Moon, where they used the Lunar Rover Vehicle to drive for almost 27 kilometres and to collect a total of about 96 kilograms of Lunar samples. The total flight duration was over eleven days (NASA, 2007).

Apollo 17 was the final human Lunar mission, launched on the 7th of December in 1972. Over three days have been spent on the Lunar surface, investigating possible young volcanic activities. This mission was the longest manned Lunar flight and the last human mission to the Moon. The final flight duration was twelve days (NASA, 2007).

3.2. Future Human Lunar Missions

Human Lunar missions have been planned by several organizations, but canceled afterwards for political reasons. In this section, the reader will be given a short overview of planned human Lunar missions that are still ungoing (P. Harris, 1992).

The first planned mission is for 2018, Deep Space Expedition Alpha (DSE-Alpha). This mission will be commercially developed, in order to fly space tourists around the Moon. Space Adventures Ltd. is the organizer, and the idea is to dock a Soyuz capsule with a booster rocket in orbit around the Earth, after which the spacecraft is supposed to circle around the Moon once, before re-entry back on Earth. There is a lot of skepticism with respect to this project; some people are speculating that the trajectory plan is not correct and that the mass has not been calculated correctly. The price would be about $ 100 million per seat. One crew member and tow passengers will be able to be on-board, with a total flight duration of nine days (K. Than, 2005).

The second mission that has been planned to send humans to the Lunar environment, is Exploration Mission 2 (EM-2) with an expected launch date after 2021. NASA's mission includes the Orion on the Space Launch System, carrying the crew to perform a flyby of a captured asteroid in Lunar orbit, as part of the Asteroid Redirection Mission (ARM) (NASA, 2015). Since the concept of ARM changed to grabbing a boulder from an asteroid instead, future plans for the Lunar flyby are still on hold.

The next planned human Lunar mission is part of the so-called Aurora Programme, with an expected launch date beyond 2024. This programme by the European Space Agency, is making a long-term exploration plan, promoting both human spacecraft and robotics. With the Aurora Programme ungoing, ESA's plans are currently mostly focused on ExoMars and its Mars sample return mission. The program was aiming for a five-year during commitment from participating states from 2001, after which they could still possibly pull out. The current situation is more focused on theoretical research, than hands-on mission planning (P. Messina et al, 2006).

The final actual planned human Lunar mission, is part of the Chinese Lunar Exploration Program (CLEP). This is part of the Chang'e program, produced by China National Space Administration (CNSA). The program consists of several missions, with Chang'e 5 planned for 2017 with a sample return mission. Expectations are that between 2025 and 2030, humans will be landing on the Lunar surface as part of CLEP (CNSE, 2007).

Other missions aiming for the Moon are fully robotic. Even though they will likely not provide more research on humans on the Lunar surface, they are planning to bring back samples, giving researchers the opportunity to study the geology at the South Pole of the Moon in more depth before sending humans. Lunar Mission Two would be a great addition to this research (The Planetary Society, 2014).

4

WHY THE SOUTH POLE OF THE MOON

In order to create a good overview of the choice for the South Pole of the Moon for a human Lunar base, more emphasis should be given on how the Moon formed, although this has not fully been proven yet.

More than one theory exist on the formation of the Moon. Several proposed theories are stated below:

- *The Fission Theory:* The Moon used to be part of the Earth and separated from the Earth in the early Solar System history (NASA, 2015);

- *The Capture Theory:* This theory suggests that the Moon was formed away from the Earth, and was later captured by the Earth's gravitational field. The Moon's different chemical composition would explain this theory, but it would mean that the capture must have been very precise and many scientists do not agree (Walt Robinson, 2005);

- *The Condensation Theory:* This theory suggests that both the Moon and the Earth condensed together from the original nebula that the Solar System arose from, although this would mean that there should be a similar composition, under which an iron core on which most scientists do not agree on (Walt Robinson, 2005);

- *The Colliding Planetesimals Theory:* Large parts of rocks, such as asteroids, called planetesimals, are believed to have interacted orbiting the Earth and the Sun. This theory suggests that the Moon condensed from this debris (Walt Robinson, 2005);

- *The Ejected Ring Theory:* This is by far the most popular theory under scientists, suggesting that a planetesimal with the size of Mars hit the Earth after the formation of the Solar System. As a consequence large volumes of heated material from the outer layers of both bodies was ejected, of which the Moon was formed in orbit around the Earth. Evidence is found in several places in the solar system that such collisions were common and it would explain why the Moon is made mostly of rock (J. Matson, 2013).

Despite the theory, the following facts should be correct according to it, no matter what:

- The Moon's low density (3,3g/cc) shows that it does not have a substantial iron core such as the Earth does;

- Moon rocks contain few volatile substances, such as water, which implies extra baking of the lunar surface relative to that of the Earth;

- The relative abundance of oxygen isotopes on Earth and the Moon are identical, which suggests that the Earth and the Moon formed at the same distance of the Sun (NASA, 2015).

Studying rock from deep below the surface, will allow scientists to understand more about the geological composition of the Moon, giving more information in order to find out whether the origins are shared with the Earth.

Since the development of the Apollo missions, scientists have been considering the possibility of a permanently manned Lunar base. With a gravity of 0,16 of Earths gravitational field, using the Moon as a spaceport could lower the cost of space exploration. Fueling and launching rockets from or near the Moon would make the process more economically efficient.

The South Pole of the Moon has been considered for a possible site for a lunar base before, considering its stable temperature, the possible availability of water, hydrogen and other useful chemical nearby, the regular exposure to sunlight - a few hundred days with eclipse durations of less than 50-70 hours -, and permanently shadowed craters for geological research. To be more specific, the Moon's axis of rotation is close to being perpendicular to the ecliptic plane, so that the radius of the Moon's polar circles is less than 50 kilometer (P. Moore, 1981). The possible base could be purely powered by solar energy. A radar experiment by the Clementine mission, proves a high possibility of water ice around the South Pole. Furthermore, the Lunar Prospector found enhanced hydrogen abundances at this location. A possible limitation of the South Pole region is possible electrical charge by incoming solar wind, causing a voltage difference in electrical equipment.

Solar particles and cosmic rays will still be a big risk, just like it will be at other locations on the Moon. Shielding could be a solution for the problem, possibly even using lunar surface material. Lunar Mission One will provide important information on the possibility of a human Lunar base on the South Pole, providing further details on the Lunar environment in this region by drilling deep under its Surface. More specific information on Lunar geology will be given in the next subsection (Lunar Mission One, 2015).

A specific landing location will not be defined in this report, but based on previous mission studies, such as for the Lunar Lander, options include the area of the Shackleton crater and Mons Malapert. All the possible landing sites lie on, or just within, the rim of the giant South Pole-aitken (SPA) impact basin. This are is of great interest because of the local regoliths that may contain fragments of SPA melt. Those regoliths could be used to date the basin, which would be a significant event in Lunar geological history (ESA, 1992). In the longer term, the volatiles that may be retained in the cold polar regoliths, could be of scientific and even practical interest, but this will be further discussed in the ISRU subsection in this chapter.

According to findings for the Lunar Lander mission, the near-surface environment of potential polar landing sites are likely to be similar, covered with several meters of unconsolidated regolith. This could possibly contain blocks of more competent materials. The materials just under the surface might be different below the different landing sites though.

The Shackleton crater for example, is an impact crater with a 20 kilometer diameter, and the surface close to the rim will probably exist of deposits derived from a depth of about 2 kilometer below the ground level before the impact found place. An interior ring of SPA could be formed. Mons Malapert, on the other hand, may exist of a pre-SPA highland crust, covered by SPA ejected material. According to NASA's Exploration Systems Architecture Study, Mons Malapert offers several advantages for a human base. It is exposed to the Sun most of the time due to the Moon's uneven surface, it is close to Shackleton Crater which is valuable for astronomical observations and communications between the sites is possible, nearby craters such as Shoemaker are in constant shadow, with an elevation of 5,000 meters line of sight communications are possible for most Lunar areas and to the Earth, and the SPA basin is located at the Lunar south pole. This is the largest known impact crater in the Solar System, as well as the biggest and oldest one on the Moon. In figure 4.1 the location of Shackleton Crater and Mons Malapert can be seen with respect to one another (D. Paul et al, 2008).

Different landing sites will have different considerations, and more work needs to be conducted on the geological environments of all the potential landing sites. The outcome of Lunar Mission One will be of great importance, providing the scientists with samples from deeper than 20 meters below the surface.

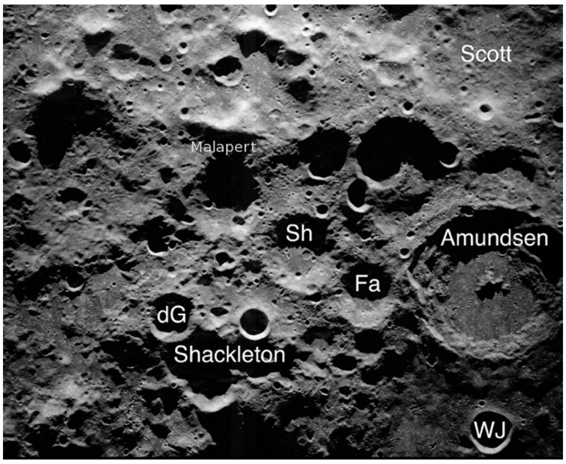

Figure 4.1: Location of Shackleton Crater and Mons Malapert (NASA, 2015)

4.1. Geology of the Lunar South Pole surface

The South Pole of the Moon is heavily cratered and part of the southern highlands. As mentioned before, sunlight is always at low incidence at the poles, which can create a more difficult situation to make estimations for geologists. Because certain regions are in permanent shadow, radar images help to interpret more information and give a more complete image of the geology of the Lunar South Pole. Data obtained from Clementine and Lunar Prospector Missions were of great help analyzing the Moon's surface.

The so-called South Pole-Aitken basin is one of the oldest and largest basins on the Moon, with a diameter of 2600 kilometer, and an average depth of 12 kilometers. Formation happened after the curst had solidified, and the basin is estimated to be no older than about 4,3 Ga. This site is of great interest, since geologists have expressed the possibility that the basin excavated part of the Lunar crust, and possibly even the upper mantle of the Moon. In order to find out about the Moon's origin, it is of high priority to sample the melt ejecta of this basin (D. Paul et al, 2008).

The Shackleton Crater is located inside the rim of the SPA basin, where it seems to be split into two segments; the rim crest about 200 kilometers towards the near side of the pole, and the Crater itself. The massifs in the basin rim crest, the Liebnitz Mountains, represent a basin rim themselves. The Shackleton Crater is located on a basin mountain within the SPA, estimated is that the massif rises 1-2,5 kilometers above the mean Lunar radius. This while elevations of the main topographic rim crest can exceed 5 kilometers (NASA, 2014).

The terrain in the South Pole contains of very rugged highlands with impact craters of a wide variety of ages. Craters of more than 10 kilometers in size can be found, including abundant basin secondary craters that were formed in different time periods. Several of the older large craters seem filled with cratered plains deposits and became smooth highland (NASA, 2014).

The Shackleton Crater is of special interest for most geologists, mainly because of its location central in the South Pole and its permanent Sun shadow. The interior is expected to contain a flat floor with a diameter of about 10 kilometers. Another main interest is the estimation of the age of the Shackleton Crater. There is a possibility to find out, especially since expected is that it served as a 'cold trap' to collect volatiles. Inferred Hydrogen might be found in the permanent shadows stability, if it is present as water ice. In figure 4.2 can be seen that the illumination level on the floor of the Shackleton Crater is zero (ESA, 2015). This image was taken by ESA's SMART-1.

In order to find out if the Shackleton Crater is indeed a candidate for a so-called 'cold trap', the age is of great importance. Initially it was thought that the crater formed between 1,0-3,3 Ga, by analyzing available mapping. In this case it would have been recently formed, and would have had little time to collect extra-Lunar volatile material. With imagery from the SMART-1 mission performed by ESA, the number of superposed im-

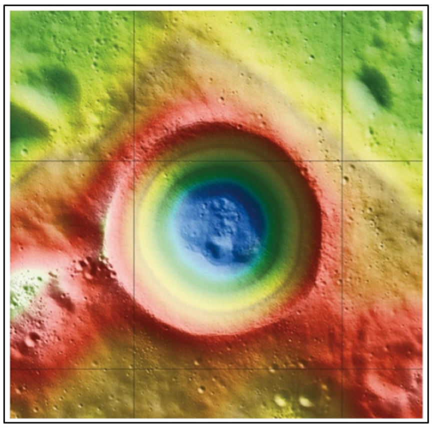

Figure 4.2: Illumination level within and around the Shackleton Crater (ESA 2015)

pact craters in the area have been counted, the more impact craters present, the older the surface is expected to be. The data obtained by ESA proved that the Shackleton Crater is older than previously thought, indicating a great crater density, and an age estimation of 3,6 Ga. In order to give more clarity on the exact age of the crater, more research will have to be done, possibly ground samples that could be made by Lunar Mission Two. Assuming that the floor of the Shackleton Crater has been in permanent shadow for the last 2 billion years because of the changing orientation of the spin axis of the Moon, this location is of great interest for future exploration, bot from the surface and from orbit, and could be a great location for permanent human presence (ESA, 2015).

4.2. ISRU Possibilities

In order to develop a cost effective Lunar base, it will be important to be able to utilize the natural resources of the Moon, In-Situ Resource Utilization. Self-sustainability will be crucial for the long duration missions, inducing both a mass and cost reduction for future missions. A challenge includes the technology readiness level (TRL), considering that this has not been done before. This section will explain more about Lunar ISRU possibilities, not too much in detail (Allen et al, 1999).

Lunar regolith can be used for radiation shielding and projection from dust. Unprocessed Lunar material can be used for thermal isolation, heat storage, and ballast mass for certain operations. The greatest use of the Lunar resources, will probably be the production of rocket propellants. Locally produced oxygen could be used for rocket propulsion, and could be the greatest cost and mas saving of the Lunar resources. If the existence of water at the Lunar poles could be confirmed, the mission scenario's could be altered. Access to the ice deposits would be a requirement, and the ice will need to be mined and correctly processed (McKay et al, 1992). In figure 4.3 can be seen what Lunar resources can be used in for different purposes.

It is almost certain that the bulk raw material for the Lunar resources will be a complex mix of rocks, minerals, and glasses. Samples from the Apollo and Luna missions prove this complexity, and most rocks found in the highlands turned out to be polymict breccias. The minerals found at the Moon are mostly tightly intergrown and difficult to separate from each other. Any further concentration beyond mechanical mineral separation will require chemical destruction of the mineral or glass containing the element by a certain process. Dissolution, melting, or evaporation could do this (Allen et al, 1999).

The main Lunar resources, Regolith, Oxygen, Hydrogen, Iron, Aluminum, and Helium-3, will be explained in further detail.

Regolith can be used to produce shieling from Galactic Cosmic Rays (GCR) and Solar Particle Events (SPE). Unprocessed bulk regolith could be used. The processing of this bulk of regolith could make glass or ceramics.

	RESOURCE	POTENTIAL USE
ENVIRONMENT	Solar radiation	Power
	Vacuum	Materials processing
	Low gravity (1/6g)	Materials processing
SURFACE	Bulk soil/Regolith	Radiation shielding
	Oxygen	Propellant, life support
	Water Ice (unproven)	Propellant, life support
	Metals	Construction of facilities and equipment
	Non-metals	Solar cells and other equipment
	Melted, sintered soil	Construction of roads and caves
	Hydrogen	Propellant
	Lava tubes	Thermal protection, radiation shielding
	Helium-3	Fusion power

Figure 4.3: Lunar Resources and different purposes (Allen et al, 1999)

A final use could be of the minerals separated from regolith for feedstock or other processing. Regolith is the most readily available Lunar material and has a broad range of chemical and mineralogical composition.

Lunar Oxygen can be used for purposes such as oxidizer in rocket propellants. Liquid O2 (LOX) / Liquid Hydrogen (LH2) rockets are considered as most likely. Other liquid propellant mixtures that involve oxygen can be considered as well. Oxygen is almost nonexistent as a free gas on the Moon. Oxygen production must be extracted from silicate or oxide minerals. Expected is that the mineral concentration at the Lunar Poles will be the highest.

Hydrogen can be used for different categories. First of all, it can be used for LOX propellant and other H-based products. Furthermore, it can serve as a reactant for reducing oxygen from Lunar soils, and it can be used for water production. Hydrogen is a major element of the solar wind, and comes in small amounts in the Lunar surface regolith. H2 can be extracted by heating, although large amounts of regolith will be needed to collect small amounts of gas.

Iron can be used for structures, although its high weight can make it less attractive. Iron could be extracted as a by-product before aluminum and glass plants would be in operation. Iron is common in many Lunar minerals and even occurs as small metal beads and fragments in the regolith. Separation of the iron metal from the regolith is complicated though.

Aluminum can be used as a coating metal, rocket fuel or even structural material. The production from Aluminum metal will not be practical on the Moon though, considering that a large support of a complex will be needed. Aluminum is found in the feldspar mineral plagioclase. This mineral is abundant in the highland areas such as Mons Malapert.

Helium-3 can be used for the development of nuclear fusion energy. It can be found as a product within the solar wind implantation in the regolith particles. The amounts are very small, but is more than found on the Earth.

A picture of Lunar regolith taken from the Lunar Mare, can be seen in figure 4.4 and is expected to be similar to the regolith on the Lunar South Pole (McKay et al, 1992)

4.3. South Pole Lunar Environment for human beings

Humans will make up Lunar Mission three. Assuming the flight duration will be about three months, as mentioned in Chapter five, the crew will need assistance to stay alive. The Lunar environment is drastically different form the Earth's, and radiation and meteoroids are a great hazard to human safety. Such dangers could be mitigated through shielding with Lunar materials, or the use of underground habitats.

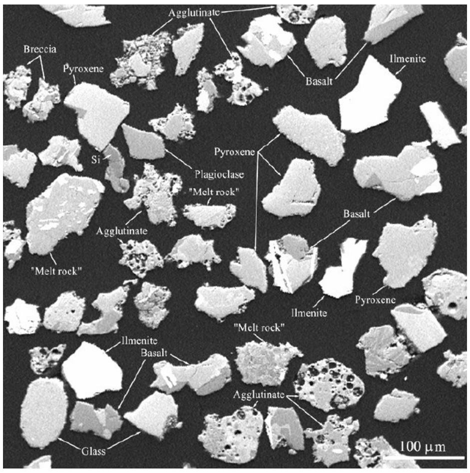

Figure 4.4: A Regolith sample from the Lunar Mare (NASA, 2007)

The moon is smaller than the Earth, and is significantly less dense. The Moon's surface gravity is one-sixth of the Earth's, and with this lower escape velocity, the Moon cannot maintain a significant atmosphere. With the lack of an atmospheric buffer, the surface temperature varies over several hundred degrees of Celsius between the day/night cycle. One full rotation about its axis, a complete lunar day, is about 27-1/3 of a day on Earth. Those are important factors for astronauts, considering that they will need to adapt to the Lunar environment. The underground habitats could be a solution here as well, considering that the Earth's day/night cycle could be faked from this position (A. Chicarro et al, 1992).

The Moon is geologically inactive compared to the Earth, seismic activity is almost non-existent, and water and atmospheric processes are unknown. This can affect the astronauts from a mental point of view, considering that the Moon is nothing like what they are used to.

Three types of ionizing radiation happen at the Moon's surface. Solar wind and Solar flares, are produced by the Sun. The third type is known as Galactic Cosmic Rays.

The solarwind is natural plasma with an average velocity of 400 km/sec. The plasma consists of a constant flux of charged particles, mainly electrons and protons, plus ions.

A solar flare can be similar to this solar wind, but the individual particles have a higher energy. The frequency of the flares may be related to the known 11-year solar cycle.

Galactic Cosmic Rays are isotropically produced outside the solar system. They are made up of high energy particles, consisting of protons, electrons, plus heavy nuclei, and gamma rays. Since the Moon receives a higher intensity of those Cosmic Rays, the astronauts will be in constant danger. The Earth is protected by its atmosphere and the magnetic field, lacking on the Moon (R. Tangum, 1992) .

An effect that is not easy to describe, is that the astronauts on the Moon will see the Earth as a small, blue dot from the Moon's surface. Their home planet will look very fragile from this distance, which can make them afraid or more conscious when coming back on Earth. This effect has been experienced by Apollo astronauts and will be a factor during future missions (NASA, 2007).

5

Lunar Mission Three Mission Planning

In this chapter, Lunar Mission Three will be outlined and an overview of possibilities will be given. Certain assumptions are made, of which the dates will be the most important ones. The realization of Lunar Mission Three will mostly depend on the success of Lunar Mission One and Lunar Mission Two and the revenues along the way. It is assumed that those two missions will be successful, and Lunar Mission Three will happen. Furthermore is assumed that Lunar Mission One will take place in 2024, and Lunar Mission Two in 2030, since more information on a possible launch date is lacking and this will give enough time for the mission to be realized, if the development starts during Lunar Mission One. Finally, Lunar Mission Three will be aiming for a launch in 2035, which leaves enough planning for the mission and the first crews to be trained (Lunar Mission One, 2015).

The concept is that six people from all over the world will be able to be part of the Lunar crew on the South Pole for three months, after which the next crew comes to this site. This will not only stimulate people from all over the planet to get involved, but will also give a bigger number the chance to go to the Moon, be part of scientific research, and give back the experience to the Earth.

How the selection process will happen, is unknown and will need further thought. One of the possibilities is to let people buy a ticket, resembling commercial space companies such as SpaceX, who announced to offer tickets to Mars in the near future. Another option is to have a common fund, such as the Lunar Missions Fund, existing of worldwide donations and sponsors, and select people to be part of the mission. The reason could be to do specific scientific experiments, or even to send people such as politicians in order to reach a bigger public back on Earth. The crew selection is not of great importance for the rest of the mission planning, assuming that the chosen crew will be healthy, fit to fly, and able to do necessary tasks.

Given that the escape velocity of the Moon is only 0,16 percent of that at the Earth, a Lunar base can be a first step in future space missions, enabling the weight and cost to go down.

5.1. Lunar Mission Planning General

Space Mission Engineering is a process in which research is done on the probability that certain mission parameters and requirements can be met with a minimum cost and risk. Mission Planning allows a feasibility assessment, used in order to find out if particular objective is achievable and to limit its complexity. A broad design of the mission can provide the information, which will be seen in the sections below.

After deciding on specific parameters and selecting the launch method, trajectory and landing method, a more specific systems engineering process can be started. This is not the purpose of this feasibility assessment. Normally this process can be done in several ways, but the most popular method in Europe and the United States, uses a so-called Concurrent Design Facility (CDF).

The CDF uses concurrent engineering methodology to perform effective, fast, and cheap space mission studies with the help of computers, multimedia devices and software tools. The studies in the CDF are mostly assessment studies, based on phase 0 or pre-phase A. Phase 0 mostly consist of the identification and characterization of the mission, in terms of needs, expected performance and expected cost. Operational constraints and assessment of project management data are reviewed. Concurrent Engineering is a systematic approach to mission development, with the emphasis on customer expectations. It involves the perspective of all different subgroups simultaneously from the beginning of the planning phase.

Concurrent engineering includes five different main factors; it involves a process, a multidisciplinary team, an integrated design model, a facility, and a software infrastructure. Spreadsheets are used for mathematical models for spacecraft design. Different design options and analysis can be performed by multiple design iterations, giving the opportunity to find the best option in the most efficient way for multiple parameters. The teams working together normally consist of Mission, Propulsion, Power, Payload, Communications, Cost, Thermal, Attitude Control, Structures and System/Configuration (ESA, 2015).

The commonly used system is to work in phases. Starting with Phase 0, and ending with Phase F, as seen in figure 5.1 below. Different Technology Readiness Levels are reached in those phases, ranking from 1 to 9. This is a method of estimating the technology maturity.1 stands for basic technology research, 9 stands for system test, launch and operation (SMAD, 2011).

Phase	Definition	TRL to be reached
0	Mission Analysis	1-2
A	Feasibility	2-3
B	Preliminary Design/Definition	4-5
C	Detailed Design/Definition	6-8
D	Production	
E	Acceptance (E1); Utilization (E2)	9
F	Disposal	

Figure 5.1: Different Mission Engineering Phases (SMAD 2011)

Since an actual spacecraft is normally designed during this process, this will not be covered in this report. The focus is more on the top layer Mission planning, ranging from Launch to operations, described in a general way. It will be part of Phase zero, mission analysis and Feasibility study of the Mission.

In order to construct a lunar base, transportation systems will be required to carry personnel and materials to the Moon. For crewed missions, the transportation time from Earth to the Moon, will need to be as short as possible. High safety requirements are mandatory, unlike for cargo missions. The different phases will be further discussed in the next section.

5.2. Different Mission Planning Stages

Depending on the mission requirements, certain mission elements can be combined. A Lunar Transfer Vehicle (LTV) might also be used as a Lunar Landing Vehicle (LLV). In this report, the mission requirements will be constraint by possibilities of Lunar Mission Two. Assuming that during Lunar Mission Two, equipment for ISRU is already brought to the Lunar surface, less cargo will be needed for Lunar Mission Three and re-supply will mostly be focused of food, clothes, and waste removal. In the next two sections, the plan for the single but repeatable manned mission will be given. Since the scope of the report is general, sections such as thermal control, and Lunar Surface Vehicles will not be discussed in detail. The top level mission requirements for the human part of Lunar Mission Three, are:

- The spacecraft shall carry six people to the South Pole of the Moon;
- The exact landing locations is not specified, but shall be in the vicinity of mons Malapert;
- The crew shall stay around the landing location for three months;
- The mission shall be repeatable;
- The launch date should be in 2035.

5.2.1. Launch and Trajectory

The Moon revolves around the Earth in an elliptical orbit with a semi-major axis of 384,400 kilometers. The Earth's equator is inclined to the ecliptic by 23,5 degrees, and the equatorial plan is relatively stationary. The Moon's orbit can be described by six classical orbital elements, when seen from the center of the Earth. Those are:

a - Semi-major axis
i - Inclination
ω - Argument of Perigee
e - Eccentricity
Ω - Longitude of the ascending node
α - True anomaly (W. Larson, 1999)

The ascending node is the node where the Moon crosses the ecliptic from south to north, the descending node is where the Moon crosses from north to south. The Lunar orbital elements are constantly changing and the perturbations of the Moon's motion include: //

- A seven hour variation of the sideric period of 27,31 days;
- Evection, small periodic changes in the orbital eccentricity, at intervals of 31,8 days;
- Westward rotation of the line of nodes, completing one revolution in 18,6 years, seen in figure 5.2;
- The variation of the inclination of the Moon's orbit to the eclipse with 5-5,3 degrees;
- Rotation of the line of apsides, causing the argument of perigee, ω, to change by 360 degrees in 8,9 years (W. Larson, 1999).

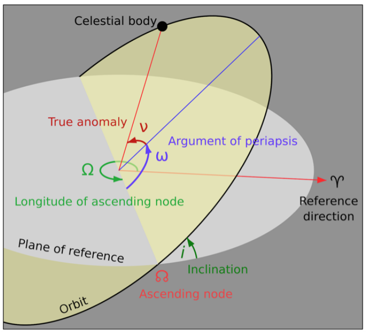

Figure 5.2: Rotation of the ascending node (GFDL, 2007)

For the determination of launch, transfer, and landing phases of lunar missions, two influences of the Earth-Moon system orbital dynamics have to be considered:

- The nodal regression of inclined Earth orbits due to the oblateness of the Earth;
- The angular motion of the Moon about the Earth.

$$\frac{d\Omega}{dt} = \frac{360°}{T}\frac{3}{2}J^2\left(\frac{R^2}{(a^2(1-\varepsilon^2))}\right)\cos i$$

with the orbit duration T:

$$T = \frac{2\pi}{\frac{3}{2}a\sqrt{\gamma M}}$$

a = semi-major axis of the orbit
i = inclination of the orbit
M = mass of the central body
ε = eccentricity of the orbit
γ = 6,67 $10^{-11}\ m^3$ / kg s^2 (gravitational constant)

Figure 5.3: Equation for nodal regression (Self)

		EARTH	MOON
MEAN RADIUS	R	6,370 KM	1,738 km
OBLATENESS COEFFICIENT	J_2	$1082{,}28 \cdot 10^{-6}$	$212{,}5 \cdot 10^{-6}$
MASS	M	$5{,}976 \cdot 10^{24} kg$	$7{,}353 \cdot 10^{22}\ kg$

Figure 5.4: Mean Radius, Mass, and Oblateness Coefficient of Moon and Earth (W. Larson, 1999)

The general equation for nodal regression, $d\Omega/dt$ in [deg / day] can be written as seein in figure 5.3
This equation can be used for both Earth and lunar orbits, using the values as seen below in figure 5.4

The next factor to be considered is the terrestrial launch site. The major constraint is the Earth orbit inclination. The latitude of the launch site is the minimum inclination that can be achieved without major performance penalties. Another limitation in achieving an inclination, is that some launch sites are near inhabited areas and have restrictions on the launch azimuth. Since the payload mass is unknown and the launch vehicle selection will depend on the financial aids, it is difficult to come up with options. The only crew module that has enough space for a six man crew, is SpaceX's Orion Crew Module, which will be able to seat seven people. In this case, the Falcon 9 v 1.1 could probably be used as a launch vehicle, although it will need more testing and the launch site would still be undecided on. Political arguments can be brought in as well, since Lunar Mission Three is meant to be a worldwide concept, and both the Dragon capsule and the Falcon 9 will be produced in the United States (SpaceX, 2015).

First, several mission profiles were considered. With the data from the Apollo missions, taking the different landing location into account, a mission profile has been made up. After Launch, a trans-lunar injection or low energy trajectory is performed, setting up the spacecraft on a trajectory that will arrive at the Moon. This is where a Landing Module will dock before separation, a midcourse correction, and a lunar orbit insertion in the polar orbit takes place. Since the initial orbital injection is reliant on the mission profile of the selected launch vehicle's primary payload, this segment of the mission is mostly a source of considerable mission risk. Thus, an ability to transfer from the initial orbit to the desired mission orbit is required to mitigate and reduce this risk.

Typical lunar transfer trajectories approach Hohmann transfers, but low-energy transfers could be used as well. A fast Hohmann transfer is more practical when performing a short duration mission without great perturbations from outside the Earth-Moon system. Figure 5.5 shows the principles of the Trans Lunar Injection (R. Riesbroek et al, 2000). Difficulties are found making this report with the orbital injection. Unmanned spacecraft have landed in the right landing area, but no manned spacecraft have been here. Future research in more detail on this topic is needed in order to provide the perfect trajectory. The given trajectory is general and will not cover all the detailed aspects.

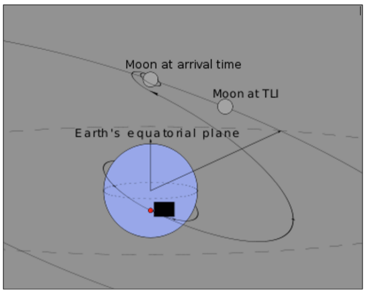

Figure 5.5: Principles of a Trans Lunar Injection (GFDL, 2007)

5.2.2. LANDING

There are two different possibilities for humans to land on the moon; a direct landing, or establishment of a lunar parking orbit prior to landing. In order to make a precise landing, being in a parking orbit before landing can make a difference, allowing mission staging in the lunar orbit or more imaging before securing the landing site. A landing vehicle may descent to the surface, while the Earth return stage stays in orbit until rendezvous, also called Lunar Orbit Rendezvous (LOR). This technique has been used during the Apollo program (J. Stecklein et al, 1992). Polar sites are always accessible from polar orbits. In case of long duration missions, more research will have to be put in an autonomous Earth return stage, allowing the crew to be on the Moon's surface for the full three months, without having a pilot waiting for them in the polar orbit. Since the longest manned Lunar mission was not beyond twelve days, such designs have not been produced yet.

In figure 5.6 a picture of the Apollo Lunar Module can be found, in which the crew safely landed on the Moon, and took off afterwards.

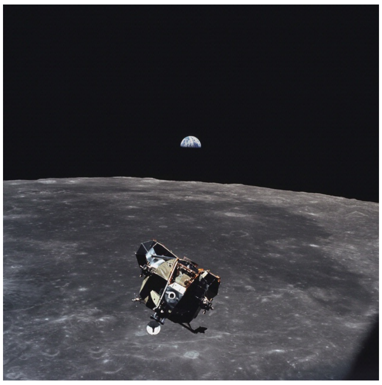

Figure 5.6: The Apollo Lunar Module before landing on the Moon's surface (NASA, 1980)

5.2.3. HUMAN NEEDS

For a Lunar base, it is important to develop a Environmental Control and Life Support System (ECLSS), in order to provide the crew with at least air, water, and food. Even if ISRU will be a possibility for future crew members, a minimum Life Support System will be necessary. The recycling of certain life support materials on the Moon can also be taken into account, so-called regenerative functions. Systems that achieve recycling, can work towards a closed loop system. The most important subsystems are: Atmosphere Management, Water Management, Food Production and Storage, Waste Management, and Medical and Safety Aspects (W. Hypes, 1992).

The main deciding factors for a life support system, are the crew size, mission duration, cabin leakage, resupply capability, power availability, volume availability, transportation costs, gravity, contamination source, and

ISRU. Considering that there have been successful human Lunar missions in the past, and that the life support on the International Space Station (ISS) has been working well, it does not seem impossible to have a working life support system for a Lunar base (NASA, 2015). Even thought distances are greater than current missions, once a base is established, the resupply can be done regularly and the crew can even work towards a closed loop system.

The main physiological challenges for humans that have been observed, include: Space motion sickness, Fluid shifts, Bone demineralization, Muscle antrophy, Hematological changes, and Hormonal changes. Considering that a new crew will spend a year on the ISS, those factors have already been tested and more information will become available in the upcoming years (W. Hypes, 1992).

5.2.4. Lunar Habitat

A Lunar habitat will be crucial for the 3 months duration missions. The structure will have to be produced on-site and will be different from what could be seen on Earth so far. The habitable portion will consist of pressurized modules, airlocks, interface nodes, a support system for the crew, and experimental payloads. The first crew to arrive might be able to bring an inflatable of light temporary module and the right tools in order to create a more decent habitat for future missions. Transportation weight, size constraints, and economic considerations require that the structural elements shipped from Earth are low mass, high strength, durable, and easily connectable. Since Extra Vehicular Activities might be limited, robotic assistance will be one of the key factors to consider (E. Haninger, 1992).

The internal pressure of the Lunar habitat will be the dominating load. The static loads from the mass and the material will be low considering the low lunar gravity. It must be able to resist the harsh Lunar environment, including solar and galactic cosmic radiation, meteorite impacts, and daily temperature variations.

The most important requirements on the structure include the adequacy to sustain long-term loads because of internal pressure, being able to withstand material degradation because of temperature changes, radiation, and other environmental affects, minimum maintenance, maximum functionality, and good heat management and rejection. An underground habitat could be a good outcome with respect to protection against the Lunar environment, but this might have negative psychological effects on the crew, considering that they might feel isolated.

Several projects have been focused on the design of habitats, as well as specific Lunar habitats. None of them have been flown in space, except for the Apollo Lunar Module, which was not designed for a duration of three moths. An interesting design, is NASA's inflatable lunar habitat proposal, as seen in figure 5.7 which has theoretically been proven as a possibility for long duration stay at the Lunar surface (NASA, 2015).

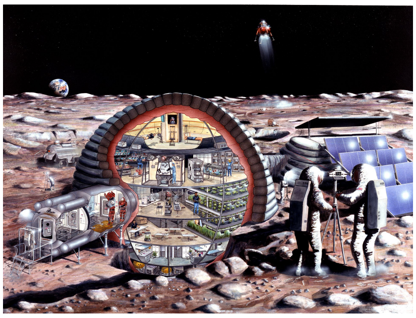

Figure 5.7: NASA's inflatable Lunar habitat proposal (NASA, 2015)

More work will have to be done on the testing of different habitats, and more research will need to be conducted on the usability of Lunar materials for such products. A habitat for six people can be tested during an analog mission on Earth, but the space environment will give a more exclusive result.

6

Financing Methods for Lunar Mission Three

The main problem of establishing a lunar base is the large required amount of money. Even though this investment would be relatively small compared with the global defense budget, this will not be a solution to the problem. A clear purpose can speed things up and Lunar Mission Ltd. will provide this.

Government funding normally occurs for political reasons, and space agencies depend on this system. When the scope of a project increases, it goes beyond the possibilities for a single nation to coop with it and several nations need to work on achieving the one goal. The ultimate prerequisite of a private investment is normally an economic return, which makes the financial situation for Lunar Mission One different and less secure. The initial development phase of the project will be of such a big scale, that great investments are needed, a situation normally supported by governmental organizations.

Different stakeholders can be part of the project. Besides the incoming revenues after the first two Lunar Mission, other parties can get involved when seeing the positive results of the previous projects. National space agencies, Major corporations, and infrastructure agencies can play a role. Unclear is what the economic return could be, but there might be an opportunity for them to be part of future space missions with the drive to make space exploration lower in cost. Overall, it is very hard to forecast how the future lunar base will be financed (P. Cohendet, 1992).

Space pioneer Krafft Ehricke identified four primary markets for lunar goods and surfaces:

- Lunar surface – Science and technology development, tourism;
- Geostationary orbit – Servicing and refuelling;
- Low-Earth orbit – Orbital manufacturing facilities;
- Earth – Lunar raw materials and finished products.

Based on those considerations, K. Ehricke defined four guiding principles for a lunar base development strategy:

- Low-cost access to the Lunar surface;
- Ample and low-cost energy assurance;
- Early self-sufficiency;

- Industrial flexibility.

(K. Ehricke, 1985)
Lunar products such as Helium, could provide an economic return during later Lunar missions. Even though the first missions will not have access to many hard machines and resources for large-scale projects, it might be a good idea to focus on Lunar exploration to demonstrate the manufacture of Lunar products.

Projects such as Lunex Project by the United States Air Force in 1958, that planned for a Lunar base, are not new. The idea was to establish a 21-airman base under the surface of the Moon, figure 6.1 shows an artistic impression of the planned Lunar base. This was before the Apollo Missions happened and the project never got realized. The estimated cost was $ 7,5 billion. Considering that Lunar Mission Three would not have a permanent presence of 21 people on the Lunar surface, the cost will be different. The outcome might even be higher, since the duration will be three moths and transportation of the crew will constantly have to be organized (Astronautics, 2002).

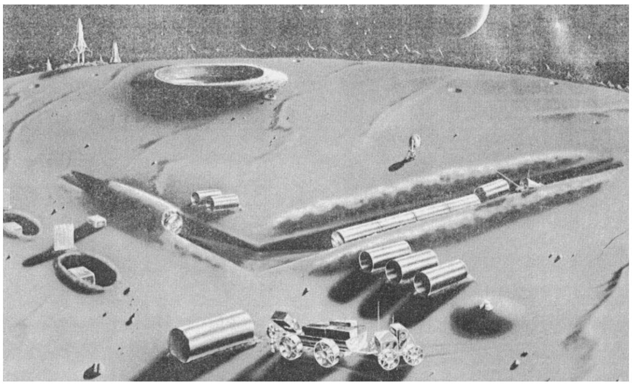

Figure 6.1: Impression of the Planned Lunex Project (US Air Force, 1958)

6.1. Future Ideas

In order to make Lunar Mission Three happen, more promotion of Lunar Mission One and Lunar Mission Two will have to who its results. Assuming that both missions will be a success, it will be of great importance to promote this success as much as possible and to share this with people all over the planet.

Politics will need to get more involved for a possible way to secure finances, which could lead to more involvement during the projects and more regulations. Their motivation will be different, but both Lunar Mission Ltd. and political organizations, would like to see tangible benefits to society, an expansion of the sphere of human activity and presence, and stimulate advances in important technologies.

Further development of other commercial space companies could benefit the financial development of Lunar Mission Three as well, showing to the world that space is accessible to all and everybody can dream to set foot on the Lunar surface.

7
FINAL ROADMAP

After outlining the background of Lunar missions and the different aspects of Lunar Mission Three, events can be placed in the right timeframe, allowing the reader to get a good overview of the work that has to be done. People have envisioned ambitious space projects for a long time, Hermann Oberth wrote in 1923 'The present state of science and technological knowledge permits the building of machines that can rise beyond the limits of the atmosphere of the Earth. After further development these machines will be capable of attaining such velocities that they – left undisturbed in the void of the ether space – will not fall back to Earth; furthermore, they will even be able to leave the zone of terrestrial attraction.' (H. Oberth, 1923) Tsiolkovsky predicted in the 20th century as well that people will live in other Solar systems (Tsiolkovsky, 1928). Now, in 2015, with an impressive established learning curve with respect to space exploration, it is time to go beyond the ISS and set ourselves new boundaries. Lunar Mission Three can be made reality by following a clear time schedule, of which the general concept can be seen in the next section.

7.1. POSSIBLE TIMELINE

Assuming that Lunar Mission Three will be developed during Lunar Mission One and Lunar Mission two, a possible launch in 2035 does not seem unrealistic. The parallel tracks within the roadmap in the next section, clearly shows how the planning of Lunar Mission Three will need to start as soon as possible .

Projects of such magnitude strongly depend on financial aids. Even the projects leading to the final mission, are of large scale and can be defining for the final outcome. For example, the analog missions and precursor missions will need to be managed and financed. There is a risk for the funding to stop in any stage of the project, and no stage cannot be funded. This will be critical for Lunar Mission One, making the financial planning a very important factor. Outcome of analog missions or technical findings can affect Lunar Mission Three as well, considering that a negative outcome of an analog will demotivate people to stay involved and will use more financial aids to find a successful alternative.

7.2. THE FINAL ROADMAP

The final roadmap can be seen in figure 7.1 and a further explanation is given below.
The Green symbols stand for events with respect to Lunar Mission One, the Orange symbols stand for events with respect to Lunar Mission Two, and the Blue symbols stand for events with respect to Lunar Mission Three. Starting of with research during the development phase of Lunar Mission One, does not only allow Lunar Mission Three to be more feasible, but will also get more people involved in the Lunar Missions, since several teams will already have to do research on related topics. After more theoretical geological research, the samples obtained by Lunar Mission Two can be analyzed and further steps can be made. It will be important to start

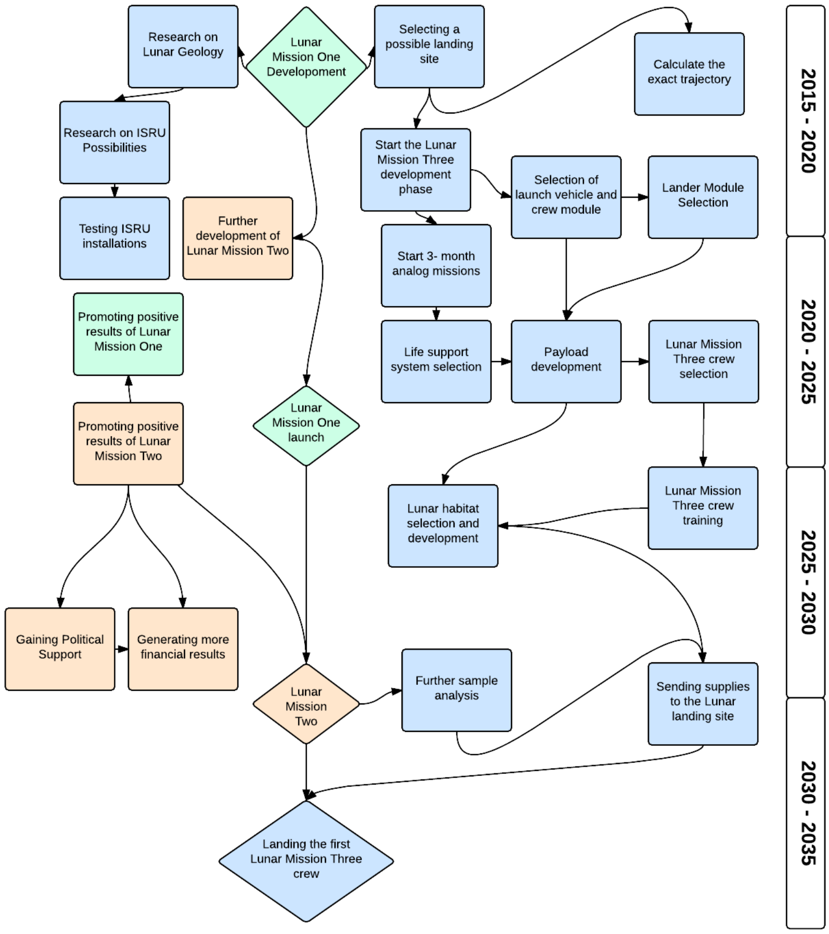

Figure 7.1: Roadmap leading to Lunar Mission Three

analog missions as soon as possible, since three months is a long time for such projects. Furthermore, it will be important to select possible crew and start their training well in advance. Those people can be involved in the development phase of Lunar Mission Three as well, gaining more knowledge on the final outcome. During all the events, it will be very important to keep promoting the Lunar Missions in order to gain more revenue and political support. After the choice for and development of the payload, the first Lunar Mission Three will be able to start.

8

Performance to Plan

In order to create a good overview of the delivered results, the performance to plan is added to this report, in which the final report will be compared with the initial Project Plan.

The mission statement was *'Indicate the feasibility of a public funded human Lunar mission, or Lunar Mission Three, in sequence with Lunar Mission One and Lunar Mission Two, in a multidisciplinary way with the focus on technological aspects and human spaceflight, thus creating a financial framework, mission architecture and roadmap for the possible Lunar Mission Three.'*.

The intent was to answer the mission statement by coming up with clear objectives and working a way through. The first objective was to identify the Lunar Missions organizations, thus creating a clear background of Lunar Mission One and Lunar Mission Two. This objective has been met by doing background research, and being in contact with sir David Iron for further information on the current status of both projects. Difficulties that have been found include a lack of information on Lunar Mission Two. Most future goals are set for five to ten years from now, but Lunar Mission Two has not been mentioned often. Furthermore, there was not much contact with RAL Space, most of the communication was via sir David Iron. This might have limited the final outcome.

The second objective was to understand and be more familiar with the Lunar South Pole for human exploration. This objective has been met by a thorough analysis of Lunar Geology, former human Lunar missions and future planned missions to the Lunar South Pole. The possibilities for ISRU have been researched and the overview helped with motivation for Lunar Mission Three. Difficulties have been found in obtaining the right information. Different sources mentioned different ages for the Shackleton Crater for example, and it was not easy to come up with a possible conclusion. Furthermore is this a very broad topic and in order to not spend half of the report on it, boundaries had to be set.

The third objective was to look at more technological aspects of the mission, especially at propulsion systems, human habitats and ISRU facilities. This has been a difficult objective since humans have never landed on the South Pole of the Moon and there was not enough time to spend too much time on specific subsystems, such as propulsion. The report does cover certain trajectory methods and approaches the objective in this manner. The section on human habitats was more general because of the lack of requirements for Lunar Mission Three. Furthermore, ISRU was part of the Lunar geology section instead, because this worked better with the final report. Kickstarter was also contacted, but they never replied the messages, making it impossible to involve them in the project. Since Lunar Mission One is a relative new project, most information on it is on their own website, there are not many sources talking about the project yet.

The fourth objective was to examine Lunar Mission Three through an interdisciplinary scope and focus on economical, financial, and legal aspects. The financial and economical aspects have been covered in a more general way since this fully depends on Lunar Mission One and Lunar Mission Two, as stated in the report. Furthermore, there was not enough space in the report to go deeper in the material, it will never be finished. The report successfully covers several disciplines, including science, applications, engineering, and finance.

It would have been good to have more time and cover disciplines such as humanities more thoroughly. This objective has been met, but in a different way than planned for.

The fifth objective was to produce a roadmap with an overview of Lunar Mission One, Lunar Mission Two and Lunar Mission Three and how they are aligned. Even though the roadmap has been produced and gives a clear overview, it was difficult to say when Lunar Mission Two would start and plan further for Lunar Mission Three. This is why most of the roadmap focuses on Lunar Mission Three, instead of the other two.

Overall, the Performance to Plan was quite accurate, although the time spend on the report was underestimated. Even though time management has not been an issue, there was much work to do at the same time and the Team Project was a dominating factor during many periods the personal schedule should have been devoted to the Individual Project. Furthermore, there were some issues wit LaTex along the way, causing some delay during the final phase of the project. Entire sections would not load, got lost and had to be done again.

9

Conclusions and Recommendations

Following on the Performance to Plan, this section will describe recommendations with respect to Lunar Mission Three that will help the project to move forward. After this section, a summary of results will be given, finished with challenges that will have to be faced in order to make Lunar Mission Three a success.

9.1. Recommendations

Some of the key challenges towards the launch of a possible Lunar Mission Three have been identified. A variety of recommendations have been made along the way that are shown in figure 9.1. For each recommendation, the correct report section is mentioned.

	RECCOMENDATION	REPORT SECTION
1	More information will need to become available on Lunar Mission Two. The planning phase will need to start soon, in order to make Lunar Mission Three possible.	2.4 – Lunar Mission Two
2	A sample return from the South Pole of the Moon will be needed in order to further analyze the geology on site. Lunar Mission Two could make this possible, if a thorough analysis will be conducted.	4.1 – Geology of the Lunar South Pole surface
3	Many processing is needed for most of the elements, and this will need to be tested in a space environment. Furthermore, there will need to be more research conducted on finding evidence for ice water at the Lunar South Pole.	4.2 – ISRU Possibilities
4	Further developments for long duration space missions will need to be monitored and adapted for Lunar Mission Three. The new ISS mission with a duration of one year will possibly give more information.	4.3 – Lunar South Pole Environment for human beings
5	Exact numbers will be needed, which can be obtained after choosing a specific launch vehicle. Political reasons for this choice will need to be considered.	5.2.1 – Launch and Trajectory
6	The only human landings on the Moon so far, have been performed during the Apollo missions. This was a crew consisting of three people, of which one remained in orbit. During Lunar Mission Three these procedures will need to be changed.	5.2.2 - Landing
7	The psychological effects on the crew will need to be researched during analog missions, especially considering the fact that they might be living underground and they might get claustrophobic.	5.2.3 – Human needs
8	There are many different designs for Lunar Habitats, but for Lunar Mission Three it might be worth considering different stages. The first few crews could use a temporary habitat, while they will build a more permanent one using materials on the Lunar surface.	5.2.4 – Lunar Habitat
9	In order to create a complete picture on the financing of Lunar Mission Three, more inside information is necessary with respect to Lunar Mission One and Lunar Mission Three. The revenues along the way will strongly depend on the first two missions.	6 – Financing Methods for Lunar Mission Three
10	The final roadmap takes many assumptions into account, making it less accurate. Once developments are actualized or changed, the roadmap should be updated immediately.	7 – Final Roadmap

Figure 9.1: Recommendations for Lunar Mission Three

9.2. SUMMARY OF THE KEY POINTS

With intense public involvement, Lunar Mission One is on its way to become the first space mission fully independent of governmental organizations. Besides the goal to perform life-changing science, it wants to reach educational institutions in order to gain interest in space exploration. Even with these noble goals, money is needed to bring it to a success and a steady income stream would be a very optimistic situation. Assuming that Lunar Mission One and Lunar Mission Two will be successful, this report has been assessing the feasibility of Lunar Mission Three, the possibility of a human base at the South Pole of the Moon.

After successfully raising £672,447 via a Kickstarter campaign, Lunar Mission One gained success and moved on to the next phace, consisting of the project management and program planning period. With endorsers including Stephen Hawking, Brian Cox, and many others, it plans to gain even more popularity along the way.

Lunar Mission Three will be able to build bridges between nations, beyond political relations. A project of such a scale cannot use national boundaries and will therefore depend on worldwide cooperation.

Lunar Missions Ltd. Claims to be on its way to find out how the Moon originated, and if the 'Ejected Ring Theory' is the right one. Besides learning more about the Moon, the goal is to learn more about the Earth and preserving achievements made on this planet by using a public archive, and burying it in the drill hole made by instruments during Lunar Mission One.

With the technical design of the mission taken over by RAL Space, a mission analysis has been provided and with a final cost of about £600 million, the mission is found feasible by this company.

Future objectives of Lunar Mission One include the scientific developments of the public archive, launching the main sails and marketing campaign, and involving more schools in to the project. Eventually, this will lead to Lunar Mission Two, which includes a sample return of samples taken during Lunar Mission One.

Assuming its success, Lunar Mission Three will happen. The Lunar South Pole is of great interest for scientists because of its craters and the permanent shadow of their floors. Furthermore, this region is of specific interest for human missions, considering its stable temperatures and line-of sight communication possibilities with the Earth. Several spacecraft have mapped the Lunar South Pole, but humans have never landed in this region.

Furthermore, passed human Lunar missions have been discussed, consisting of the Apollo missions. Even though these endeavors are not completely comparable to Lunar Mission Three, they serve as an example as they have been the only ones offered. The duration was not close to three months, but their trajectory, landing, and life support system are factors Lunar Mission Three can work with. Future human Lunar missions are discussed, but most of them do not seem fully realistic and political changes and budget cuts seem to be a threat.

The South Pole of the Moon seems like one of the most interesting Lunar areas for human exploration, and with the right protection against the Lunar environment, a long duration mission does not seem unlikely to happen. Because of its heavily cratered surface, the South Pole offers a wide variety of elements, possibly usable for ISRU.

Oxygen, Water Ice, metals, Hydrogen, and other resources could possibly be obtained from the Lunar Pole, giving the crew the opportunity to work on a closed loop life support system, supporting the permanent Lunar Base concept.

With the launch of Lunar Mission One scheduled for 2024, Lunar Mission Two in 2030, Lunar Mission Three is planned to take place in 2035. The concept is that six people form all over the world will be able to be part of the Lunar crew on the South Pole of the Mon for three months, before another crew arrives. Using feasibility assessment parameters, the top-level mission stages have been described. After launch, a trans Lunar injection or low energy trajectory is performed, setting up the spacecraft on a trajectory that will arrive at the Moon. This is where the Landing Module will dock before separation, a midcourse correction, and a lunar polar orbit insertion before landing on the surface of the Moon.

Two different landing methods can be considered in a later stage, either a direct landing, or establishment of a lunar parking orbit prior to landing. The last option might provide more precision, also incase of a Lunar Orbit Rendezvous.

A lunar habitat will be crucial for the three month duration of the missions, and a structure will have to be produced on-site. The first crew to arrive might be able to bring an inflatable or light temporary module and the right tools in order to crate a more permanent habitat for later missions.

The main problem of establishing a Lunar base is the large amount of money required, even though the investment would be small compared to the global defense budget. It will be very difficult to find enough funding for Lunar Mission Three and the public revenues will only keep coming if Lunar Mission One and Lunar Mission Three will be a success.

The final roadmap clearly indicates that funding along the way is crucial, and if one phase of either the development or testing side will not work out, the mission is likely to fail. Lunar Mission Three strongly depends on public involvement along the way and it will be the task of the teams involved in Lunar Mission One and Lunar Mission Two to keep people anticipated in further development.

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