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The Reality of Space Exploration: A complete integral approach of Space Mission Design

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Overview

The exploration of space is known by many of us through different ways, yet all from very diverse fields which appear to have no linkage at all. We know what topics space exploration deals with, like engineering, astrophysics, planetary science, or economics among others, but we do not know how they are correlated in a mission. Thus, there is a lack of knowledge on how space missions are put together, the different aspects that are considered and how they are approached.

Hence, the goal of this project is to provide a framework that encapsulates the entire process of analyzing and designing space missions, offering a holistic view of space mission design rather than a local view of a specific field within it. The present work is not only from the engineering point of view but rather from an interdisciplinary approach, in which the work shows that space exploration entails much more than just engineering (Management, Astrophysics, Planetary science, Astrobiology, Economics…). The linkages within these different fields involved in space exploration missions, like the ones mentioned above, will be revealed as well as their contribution to the mission.

Along the project, the reader is guided to design a space exploration mission departing from the questioning of exploration (which is a current hot topic) recognizing the importance of exploration, understanding the actuality of the sector, and finally starting with a vague idea of a mission, up until designing, building a team, setting protocols, estimating costs, etc., ultimately designing a mission to Mars.

Resum

L'exploració de l'espai és coneguda per molts de nosaltres a través de diferents formes, tot i que totes provenen de camps molt diversos que sembla que no tenen cap relació entre si. Sabem quins temes tracta l'exploració de l'espai, com l'enginyeria, l'astrofísica, les ciències planetàries o l'economia, entre d'altres, però no sabem com estan relacionats en una missió. Per tant, hi ha una manca de coneixement sobre com es construeixen les missions espacials, els diferents aspectes que es tenen en compte i com s'aborden.

Per això, l'objectiu d'aquest projecte és proporcionar un marc que englobi tot el procés d'anàlisi i disseny de missions espacials, oferint una visió holística del disseny de missions espacials en lloc d'una visió local d'un camp específic dins d'aquest. El treball present no és només des del punt de vista de l'enginyeria, sinó que adopta una aproximació interdisciplinària, en la qual es demostra que l'exploració espacial implica molt més que només l'enginyeria (gestió, astrofísica, ciències planetàries, astrobiologia, economia...). Les connexions entre aquests diferents camps involucrats en les missions d'exploració espacial, com els esmentats anteriorment, es mostraran, així com la seva contribució a la missió.

Al llarg del projecte, el lector és guiat per dissenyar una missió d'exploració espacial a partir del qüestionament de l'exploració (que és un tema candent actual) reconeixent la importància de l'exploració, entenent l'actualitat del sector i, finalment, partint d'una idea poc acurada d'una missió, fins a dissenyar, construir un equip, establir protocols, estimar costos, etc., per acabar dissenyant una missió a Mart.

To the people that trusted this project, starting with Hector & Marina
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Contents

Preface

The reality of space exploration: A complete integral approach of Space Mission Design is a research project that explains space exploration from a rigorous and complete point of view.

In our society, the topic of exploring outer space abounds. People are constantly exposed to space exploration in the form of movies, comic books, and conspiracy theories. In this topic aliens, interstellar voyages, portals, wormholes, and other concepts far from our reality and far from our scope are what characterize space exploration.

This is not the reality of space exploration, thereupon, this project aims to explain what the current affairs in the space exploration sector are, what aspects are to be taken into account when exploring a planet or extraterrestrial body, and how are the operations managed within a space agency and other internal affairs that one is not exposed to in movies and other media because they may lack popular interest. This project aims to explain how things are done, ultimately what "*The Reality of Space Exploration"* is like.

Likewise, a new point of view is offered with new solutions to current procedures and to old missions, offering various alternatives on how a space mission could be confronted to extend the boundaries of research, already set in previous missions.

This global scope is obtained by working with experts on different fields of interest in space exploration and via the observations of books written by top scientists and researchers in the following areas: Astrodynamics, Geology, Planetary Science, Science Dissemination, Spaceflight Life Support, Astrobiology, Mission Design, among others.

Introduction

This project aims to research the different topics that involve space exploration, from questioning “why” exploring in the first place, to breaking down how a space mission is engineered, and what is considered. Thus, offering an updated framework of a Space Mission Design, that is, offering a new approach to modern space exploration missions, in line with the most advanced technologies that the industry offers nowadays.

With that goal in mind, throughout the entirety of the project, a mission of our own will be engineered, hence walking the reader through all the stages of Space Mission Engineering and all the dilemmas it involves, exploring new alternatives for space exploration.

For that reason, the research is broken down into three main parts that will guide the reader to understand why a space exploration mission is contemplated. It first introduces the human being as an *“exploring creature”,* and aims to explain why curiosity lies within the own human being, why the exploring spirit is something we should encourage in our society, why it is beneficial and ultimately, why we should explore the next frontier, outer space.

Thereupon, the next part reflects on what this next frontier is, and what fronts there are to explore, showing the process of thought when exploring and why one choice is taken instead of another. In a growing *unmanned vehicle* era, both the unmanned and the crewed type of missions are considered, and different points are exposed on the pros and cons of both alternatives.

Finally, the main part of the project is how to arrange a Space Mission (the project's development). Collaborating with other disciplines, a plan will be formulated to direct the actual Space Mission. We have considered the main parts of the design process, such as how it is designed, the different teams that lead it, the main objectives, etc., Here a new approach to how missions are designed will be exposed, concerning the main objectives and all the activities that are considered.

Part 1. We are Explorers

This part of the project is crucial for understanding everything that will be developed in the coming parts. None of it makes sense without asking in the first place the proper question: Why bother doing all of this? Is it worthwhile?

In the subsequent sections, an inquiry is conducted to examine these concepts, leading to a re-evaluation of the underlying reasoning behind exploration, with a focus on uncovering its profound significance. Following this, an analysis will be undertaken to explore the factors that have driven humanity to pursue exploration throughout history. Thereupon, a global view of where this exploring nature has led us will be re-evaluated, reflecting on the current era of Space Exploration. Overall, giving a complete knowledge of what has been done so far, thus understanding why it is so important to acknowledge everything that has been done so far in the space sector and how it brings us closer to an interplanetary future.

This section is also key to re-address an issue that Space Exploration must overcome, which is the public opinion. The public perception is, as of today, one of the biggest barriers the sector has to attempt big projects. Nowadays people are not as keen on space as they used to be when there was the *“Space Race”* between the USA and the Soviet Union. During that time, the two powers spent as many resources as they needed and nobody had a problem with that due to the popular excitement, as a flourishing affair. Nowadays, the race is between the private companies, which is now increasingly growing, also gaining part of that enthusiasm that people used to have for the space sector. However, not with enough engagement from most parts of society to perform missions of the magnitude of Apollo missions or Martian missions. There surely will be a lot of supporters for such missions, although considering the current thoughts on how economic resources are spent in the space sector, that may come with a bigger than ever number of reluctant people.

1.1. The Exploring nature of humanity

Nowadays Earth has become little for us, it is a popular thought that there is nothing more to explore, that every place has already been visited and that Earth no longer has the interest of the actual generation of explorers. However, that is not true at all, in fact we know more about Mars’ surface than the depths of the oceans on Earth [1]. The vast majority of Earth’s surface is covered by water (precisely 70,8% of it), and it is estimated that over 80% of the ocean remains unknown.

That being said, the goal of this project is not to give reasons why oceans are worth exploring, but rather why space is worth exploring. And regarding this matter, humans take for explored the vast majority of Earth. Thereupon, the new frontier is space and it already is the subject of most exploration missions and the illusion of some people.

But before anything, why bother exploring? Exploring missions tend to be arduous, deadly, time-consuming, and cost lots of money… for what? Sometimes they do not even report any earnings to their sponsors, and so all of the effort for (maybe) nothing…? The main answer is yes, exploring may not be a good investment if you are looking for profits, it does not ensure anything. Risk lies within exploration, it is a main part of what exploration is.

Knowing that exploring entails big risks, why even consider it? It could get people killed, with big costs, and a lot of effort, yet lots of people endeavor it, knowing all the consequences it could imply. For instance, the advertisement to recruit crew for the expedition Ernest Shackleton led to Antarctica between 1914 and 1916 (Figure 1.1) does not seem appealing, nonetheless, many people showed up to be part of the crew despite low wages, and relatively high chances of death, etc.


qualified. M. L. Barker. 1408 Chapman Bldg.

MEN WANTED for hazardous journey, small wages, bitter cold, long months of complete darkness, constant danger, safe return doubtful, honor and recognition in case of success.
Ernest Shackleton 4 Burlington st.

MEN—Neat-appearing young men of pleasing personality, between ages ... and 40 to work

Figure 1.1 Ernest Shackleton's advertisement in the newspapers

There seems to be something within the nature of humanity, which makes us undertake activities that do not seem to have any rationale behind (in terms of survival instinct) and which could result in death. That part of humanity is what we are studying in this section, understanding why we ultimately are keen to explore.

The human nature

It must be understood that a big part of what makes humans what we essentially are as a species, is all those matters that make us survive. We find pleasure in eating, in coupling, we feel better in watery environments and that is with many other aspects of our being, and all of this happens for most human beings. It is no wonder we find pleasure exerting such activities, if we did not perform them, we would no longer be here. It is natural selection, those individuals who did not find pleasure in eating, did not eat as much, hence not getting all the nutrients their body required and ultimately dying earlier. Those individuals who performed these activities were the ones who prospered. We are the ones who prospered, so we mostly are like this.

All these aspects that make us who we are as species are innate, it is what makes humans to be humans. One of these many aspects is our innate curiosity and fascination for things we do not quite understand, to finally unveil them. Humans are eager to know, to discover, and it is now that we can understand where we got this exploring nature, as it fundamentally is what led us to where we currently are. In other words, if we were not explorers, we would not be here as we are.

World-renowned scientific disseminator Carl Sagan stated in his book *“The Pale Blue Dot”* [2], that humans were meant to roam the cosmos. He stated that it is because the need to explore is firmly set in the genetic make up of our species, a product of what has been already mentioned in this paper, natural selection. Sagan believes we will ultimately leave Earth, and if not we may face extinction. To stay alive, every galactic civilization is obliged to become space-faring. As he says, we have little choice, binding ourselves to Earth is a foolish risk to take.

Exploration has great value for humanity, as it inspires us, widens our knowledge, and gives us hope for a better future. Also, the consequences can be worth the risk of endeavor, as exploration makes us push the boundaries of technology looking for new ways to tackle different problems. As ex-NASA engineer Mark Rober said [3] *“Reaching new heights often creates new solutions and opportunities on the ground”*. The truth is that all of this development is leading to advances in different fields of work that have nothing to do with space exploration, and that at the same time enhances life on Earth. An example of that is meteorological satellites that help to better predict the weather, internet-providing satellites that aim to provide internet anywhere on the planet, and also “small advances”, that we use in our daily life, such as cordless vacuum cleaners which were invented in the Apollo era to extract core samples of the lunar surface.

Thereupon, we can conclude that exploration does not assure money. There is no money on the Moon’s surface, yet we are about to go back [4]. But on the other hand, exploration is an investment, not in economic issues, but rather in humanity. Exploration leads to an investment in talent, in technological advancements, in solutions to problems that nobody would ever pose and overall, in improving the life of humans and our surroundings, regardless of whether it is on Earth or elsewhere.

1.2. State of the Art of Space Exploration

This section will briefly cover how space exploration is currently perceived, what are the latest advances, and what are the actual boundaries of space exploration. Knowing the latest advancements is important to know the job done up until this day, to know where we are departing from, and to know where to explore. By understanding and interpreting the data we have, we can get a better idea of where it is better to endeavor.

I. Society’s current perception of Space Exploration

As mentioned in the latter chapter, there is a large number of people who believe too much money is invested in space exploration. A public poll [5] made by Business Insider in 2018 showcases that roughly a quarter of Americans think that NASA's budget should get cut off. The position of these people is driven by the fact that the amount of money they believe is spent on NASA, is far larger than what it is in reality. People who participated in the poll believed that 6,5% of the total budget of the US government was going to NASA, but that is wildly far from reality which is 0,5% of the total budget. Hence, it is no wonder that there may be people who have this opinion towards NASA, and space exploration overall. The same survey shows that 85% of Americans would raise NASA's budget inadvertently. The result of these polls showcases that society is not well informed about how much money is spent on space and what it is spent on.

Anyhow, space exploration is still a wonder for most of society as the survey showed Mars and the Moon are still within their interests. That, and the current rise of private space companies with big ambitions, is taking back the interest in space exploration. Entrepreneurs such as Elon Musk, Jeff Bezos, Richard Branson, and many others, are showing people that space is within reach and promote a future where humanity is no longer bound uniquely to Earth, but to other worlds such as Mars or the Moon.

II. Latest Advancements

The rise of this new era of space exploration comes by the hand of private companies, and their pursuit is to make space exploration somewhat "affordable". At first, for the public eye this may not seem to have much significance for space exploration compared to the Apollo missions, but the truth is that this is fundamental for the evolution of space exploration, and further developments in making space more economical, will help endure the human presence in space.

In this topic we will introduce the **launch cost per kg** measure, which represents a way to estimate the cost of launching a payload in space. It is very important to understand how expensive is to launch a rocket, thus, to determine which is the most economical solution. The latest advancements have moved towards making this cost as low as possible, and it is thanks to private companies that this is happening. Hereby, the present work will find enlisted in Annex A the latest technological developments in terms of vehicles that can get us to outer space.

As seen in the disclosure of the latest advancements selected in this work in Annex A, the industry is getting cheaper and overall more cost-efficient, and it is coming by the hand of private companies.

III. Current Boundaries in Space Exploration

This analysis of the boundaries in space exploration will be disclosed in Annex B. The progress of rovers, orbiters, and probes around space is remarkable and must be acknowledged as they are sending very useful data regarding other worlds, improving the knowledge we have of our solar system and outer space. They help in the exploration of space and getting to know unknown worlds to humanity. Their progress represents the pinnacle of space exploration, and it is important to know from where we are departing to endeavor on the next stage of exploration.

The topics enlisted in Annex B are the main current projects that the main space agencies have on their desks to discuss. Here we are talking about outer space missions, but there are also plenty of missions to be developed right here on Earth, in fact most of them are designed to work here. For example, the mission *SMAP* [6], which measures surface soil moisture to make predictions of floods, drought seasons, climate change events, and most importantly to make predictions of agricultural productivity, which is very suitable, especially for developing countries. Like *SMAP*, there are plenty of missions whose role is to make life on Earth better. This topic will be furtherly covered in the next chapter, given that these kinds of missions are a great example of the benefits of space exploration.

1.3. Benefits of Exploring

When talking about the benefits of exploration, one basic thing comes to mind, safety. Dinosaurs' extinction is believed to have been caused in major part due to a meteorite collision. The same thing could happen to us. NASA and JPL scientists estimated it would only take an asteroid with a size of 1-2 kilometers to cause major catastrophes [7], placing the entire population of Earth at risk. However, they also projected that the likelihood of this happening is of several times per million years on average.

Here the worst scenario of potential extinction has been considered, but much smaller objects do sporadically impact Earth as big as 10 meters and have the kinetic energy of about five nuclear warheads of the size of the ones dropped on Hiroshima [7]. Moreover, to give a reference to this, the rock (20 meters wide) that struck Chelyabinsk, Russia in February 2013, which did not reach the ground as it exploded 30 kilometers above, had a shockwave that unleashed 10 times more energy than the already mentioned dropped bomb in Hiroshima.

The potential destruction of an impact depends also on the mass, the speed, and the angle of entry of the object. But the example of Chelyabinsk's meteorite has been perfect to illustrate the real need to further develop technology that helps us avoid dangerous objects. As Carl Sagan said [2] exploring is a need humanity must sustain, as the strike of an asteroid is inevitable.

As mentioned in the first chapter, space exploration is an investment in talent. Part of the money spent by NASA involving exploration is going back to society in the form of its workers, creating jobs, helping jumpstart businesses, and overall growing the American economy. As the former ISS commander, Chris Hadfield said [8], *"NASA's budget is not spent in space but right here on Earth, where it's invested in American businesses and universities, and where it also pays dividends, creating new jobs, new technologies and even whole new industries."*. Keeping up with the example of NASA (though other space agencies work similarly), the agency is very aware of the importance of giving back to the national economy and looks for ways to impact the most. Economically [9], in 2022 NASA reported that it generated more than 71,2 billion dollars in total economic output and supported more than 339 600 jobs.

Exploration is something that all of humanity has in common, there are humans nearly anywhere on Earth, including tiny islands in the Pacific. However, humans first appeared in Africa, so it is not arbitrary that we got to these places on Earth, we had the need to explore them. A good example are the *Lapitas*, [10] a neolithic culture that is said to be originated in the oriental part of China circa 10 000 years ago, and one day decided to go to the horizon and further, to seek a new place. Nobody knows the reason that pushed them to make this decision, but the fact that they undertook this trip is impressive considering that the means they had at the time were very limited, and the distances were enormous considering the vehicles they had. The result was the colonization of New Guinea, Taiwan, the Philippines all the way to the Polynesia. We are not the first explorers of our kind, we have always been exploring throughout history, from the *Lapita's,* to Christopher Columbus, and up to Neil Armstrong. We are explorers.

These examples together with the further reasoning stated throughout Part 1 show that the impact of exploring has always been beneficial for humans. It has helped us develop and, therefore, it is a venture we must undertake.

Part 2. What to Explore

Part 1 helps understand the importance of space exploration, hereby Part 2 is intended to start the exploring process. Part 1 has illustrated that the urge we feel as a species to reveal the unknown, to discover, is something natural, and in fact is an innate capacity of the human species that has made it prosper, getting to the point where we are now. Part 1 has also shown how far space exploration missions have gone, and how much we know about outer space, as well as the new technologies that are bringing us closer to a multiplanetary species by making space more “affordable”. And finally, the present work has shown the benefits space exploration implies, thus being proved it is worth the endeavor. Therefore, the project has proved that we shall explore.

This part of the research project represents the next step, which is to explore what should be considered first and foremost when thinking about a mission. However, considering the actual open fronts in exploration, we are only choosing a path to follow. Thus, crucial topics of this section are what we explore, what we are looking for, and what triggers such an endeavor.

The goal is to guide through a possible exploration process, we are now a step closer to designing a space exploration mission. However, before getting into it right away, we must know where to go, what we are seeking on the mission, what questions we want to unveil, and how we are going to endeavor it. Is it better to proceed with an unmanned mission or a crewed mission? These are the topics that will be covered in this chapter.

2.1. What to look for when exploring

The first big question that arises is, “what do we explore?”. To answer that question, it is important to know what we are looking for. What would trigger us to explore?
Nowadays, Space agencies and investors are interested in exploration for three main reasons, or more precisely for three purposes:

1. Scientific Research
2. Exploitation of natural resources
3. Missions involving safety

The first tries to answer the most daring questions about the cosmos, our existence and the history of the universe. The second, mainly led by private investors and governments, aims to know what the composition of some of the celestial bodies in our system is. Scientists look for bodies that are comprised of promising elements, such as valuable minerals, water, or other materials that could be used as propellants. Asteroids, for instance, are the primary source of these types of elements. Finally, a space exploration mission can be arranged bearing safety in mind, like the already mentioned *DART* [11] mission, which deflected the trajectory of an asteroid. These missions seek for potential objects that could endanger earth, or track events like solar flares like *DSCVR* does [12].

Being these 3 types of missions introduced, in Annex C we will consider the second one: “Exploitation of natural resources”, given that it is a feasible option in the sector. However, we will first put into question the ethics behind exploitation.

Having introduced the different purposes to explore outer space, we must make the decision of which of these purposes to choose, in order to progress with our aim to design a mission. This decision will play a big role, perhaps the biggest, in our mission as every next step will be taken with this decision in mind.

This decision is somewhat arbitrary as it depends on the performing agent’s main reason to be. In this case, as the desire is to get to know more about our existence, **we will be performing a Space exploration mission with a scientific research approach, and the extend of the mission will be to be able to set a testing facility for advanced research.** Furthermore, the intend of this mission is to represent a feat never accomplished, which is to set up a camp in another world.

2.2. Places worth exploring

The purpose of the mission is on behalf of scientific research. This decision will condition our next steps towards designing the mission. The next decision to make is what to explore. To answer that question, we will have to think of the most interesting places to explore in a scientifical manner. That is, which outer space bodies will answer more questions, or at least, the ones that we seek to reveal. A space mission must assure, as seen in [13], that after performing the mission we will know something we do not know now.

Thereupon, in this section we will analyze the different possible worlds to visit, and which can clear the most daring incognitos we have. However, there are a few restrictions we face when choosing what place to explore. A first restriction must be set, which is speed and time in space, further explained in Annex D.

Given that our aim is to explore for a scientific purpose, the research topic is what will ultimately guide us to choose the world we are visiting. In this case, it is supposed that the research subject we want to discover is whether life can sustain or originate in other worlds apart from Earth and understand better how life originated. Moreover, as NASA’s associated astrobiologist Antonio Pérez stated, [14] discovering any evidence of past or present life on Mars, would be without doubt, the biggest discovery in humanity’s history.

Such conditions exclude the ice giants and the gas giants; however, their satellites could provide an answer to these questions. Their size is at times so big that given their size they could be considered planets (see Figure 2.1), and some present promising conditions, like having water, atmosphere or even being able to hold life. The best example is Enceladus, [15] which contains a big ocean of liquid water inside and it could maybe even hold life within it.

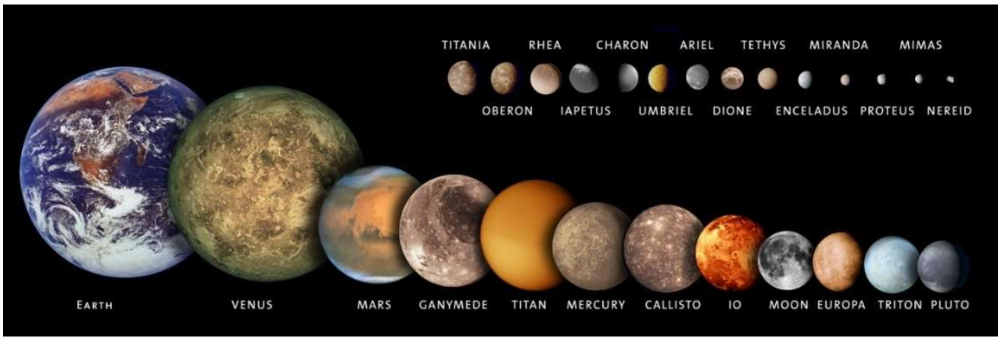

Figure 2.1. Inner solar system planets compared to the biggest satellites

Source: **752224main_Exploring_Planetary_Moons.pdf (NASA.gov)**

Nevertheless, performing missions to these worlds would require us to utilize probes as mentioned before, which is a drawback if the intention is to set up an investigation center or laboratory of some sort. Enceladus is a promising world to find the answers we are seeking but the type of mission we want to endeavor is not suited for Enceladus [15], instead it is a perfect job for a probe. In fact, in [16] Jacopo Aguzzi explores the solution of exploring Enceladus' ocean with a deep-sea sensor in search of life organisms.

Another great example of a world that could hold microbial life as we know it, is Titan, Saturn's biggest satellite. It is the only satellite that we know of that has an atmosphere which is 1.6 times that of Earth [17]. However, we need more information of Titan, a robotic mission on Titan's surface is the next step of exploring it. In fact, in [13] we get a view of a NASA and JPL team of how they design a mission to explore Titan's surface. The mission's name was Oceanus, but at the end was cut-off due high costs.

Ultimately, the most promising worlds to look for microbial life (past or present) are Mars, Enceladus, and Titan.

Mars, the selected option

If we seek life or traces of past life, albeit microbial, we have to look for water, because that is the only way we know through which life can exist (apart from life in arsenic). Regarding this matter, another world which is probably the most interesting to the scientific community is Mars.

Mars is right now the most similar planet to Earth that there is in the solar system in terms of living conditions. The Martian day (24 h 39 mins) is roughly the same as an Earth day, given the inclination of its axis it has seasons, gravity is a light 37,8% of Earth's gravity and temperatures are not very extreme compared to other worlds, it is overall the best place to stay for humans. Mars' Earth-like conditions suggest that Mars could have been someday like Earth, with oceans of liquid water and maybe even life. These oceans were mainly located in the northern hemisphere where the planet's surface is lower. The very surface of Mars gives us hints to deduce that an ocean once posed over Mars' surface, that is because it is visible that the southern hemisphere has a lot more craters than that of the northern hemisphere which has fewer, besides the ones found in the north are younger than the ones in the south. A possible explanation could be a large body of water covering the north, making it harder for meteorites to reach the depths of the ocean.

Additionally, considering the data gathered by rovers *Spirit* and *Opportunity* [18], we know that there was once acid water, flowing water, and neutral-pH-water. Other rovers and probes found compelling evidence of layers of sediments in *Gale* crater by *Curiosity* [19], caused by floods and droughts within the crater. Finally, and probably the most exciting discovery is the one already exposed in section *"1.2. State of the Art of Space Exploration"*, which is the discovery of present underground deposits of liquid water in Mars deduced from data recorded by the *Mars Express* probe and interpreted with Roberto Orosei's investigation work [20].

However, even if it does not answer our questions, further interesting questions would arise, according to Antonio Pérez those are [14]: *"How is it possible that, being so similar in the past, life has emerged on Earth and not on Mars? How is it possible that, after exchanging so much material in their history in the form of asteroids, they have not contaminated each other?".*

On the other hand, its current look of an arid lifeless (if so) world makes us question, what happened to Mars, and how. Could Earth someday transform into what is now Mars?

Mars also features [14] a great geological diversity, and it is the most accessible planet. Although Venus is closer to Earth, it is more costly to travel to the Sun rather than away from it [21], so it requires less energy to go to Mars rather than any other planet. As explained previously Mars could ultimately give us answers to the emergence and evolution of life.

In conclusion, in terms of scientific interest Mars and Enceladus are very interesting bodies to spot life, but we have more information from Mars, since many rovers and probes have circulated and orbited on and around it. In terms of feasibility, Mars is the most accessible and is the one closest to our reach in terms of technology. We have the technology to explore it how we want, whereas on the other hand the technology we would need to explore a world like Enceladus is not as developed and tested as a mission of this caliber would require.

Therefore, **the mission will be performed on Mars' surface.**

2.3. Crewed Missions & Robotic missions

As seen in the last section, the decision of sending a crewed mission or a robotic one highly influences the places we can visit. If we want to explore the sun from very close like the *Parker Solar Probe* does, it is not possible to send humans on such a mission, not with the current means. Besides, it would not be productive as this particular job can be better done with a probe than a human, and its assistance would not add much value to the mission.

This section will swiftly cover in Annex E the positive and negative aspects of these two different approaches to proceed with a mission, exposing their main differences, and when to choose one over the other. After this has been exposed, we will cover how we will proceed with the mission we want to design and why.

If a proper investigation of the Martian surface and the setting up of a stationary base camp are wanted, the best option to proceed with the mission is to bring astronauts. Such endeavor will guarantee the better collection and interpretation of materials on Mars' surface and will get us a step closer to becoming interplanetary. Astronauts will be able to cover a wider distance and interpret better the potential spots where promising discoveries can be made.

Rovers have already done their job; we now know that Mars is a promising planet that could hide within it a lot of answers to our most daring questions and hold conditions that, with the correct equipment, astronauts can withstand.

In conclusion, the choice for the mission developed in this project will be to go to Mars and explore it with a strong team of astronauts. **Now it is known where we want to go, hence it is time to start designing the mission.**

Part 3. Mission Design

Within this Part 3 lies the core of the project. Up to this point we have stated the basic needs to explore, the purpose for exploring so we now know where we are heading, thus everything left is to design a space exploration mission.

Over the whole of Part 3, a unique framework (see Figure 3.1) of how to proceed with Space mission design is going to be presented to show the reader step by step how to best prepare for a mission. Therefore, all the topics involving a space exploration mission will be discussed, presenting solutions to problems, showcasing a side of space exploration which does not get visibility in accordance with the impact it has on the mission, which is the mission design process.

Figure 3.1 Framework of space exploration mission's design

It is important to state that there are different ways of approaching mission design, because it is a subject that is ever evolving, and it molds to each mission. However, there is a general structure that can be followed, although this may vary depending on the type of mission. For example, the process of designing a communications mission differs a lot from the one we will develop. The objective is to provide a different unique approach.

The present chapter is not intended to give a technical approach, rather an approach based on the management point of view. Space mission design, it is often strictly related to Systems engineering, however, that is because most missions ever launched are robotic missions, which solely rely on systems. In this mission we rely on systems as well, but what we are designing is not the engineering systems themselves, but the way the whole mission is put together from a management point of view.

3.1. Space Mission Engineering

In this first chapter we introduce and give a detailed explanation of what the concept of "Space Mission Engineering" is, which is very important to address the whole project, and briefly describe some of the most relevant concepts of this process, though not every single detail involved in space mission design will be enlisted as this could make the project too long. But first, what is “Space Mission Engineering”? According to [22], *“Space Mission Engineering is the definition of mission parameters and refinement of requirements so as to meet the broad and often poorly defined objectives of a space mission in a timely manner at minimum cost and risk.”*

Thus, in other words, space mission engineering is to plan a mission starting from mere ideas that are vaguely detailed, just like the ones we have in this project up to this point.
Space mission design or engineering has the unique goal of managing all the different disciplines that involve a space mission, which translates into the managing difficulty it involves. The objective is to deliver a detailed process to follow when performing a mission. Mission design represents a structural part of the mission, merging all the duties to be done in one unique interdisciplinary approach. It is the “blueprint” of the mission, it represents what the architectonical plane is to a building.

Mission Objectives & Requirements

The already mentioned vague ideas of what is needed to be done have to then be translated into different **objectives** of the mission. Delivering these objectives is a key role of Space Mission Engineering and is the first step of the mission design process. However, these objectives are set in line with what there is to do in the spot where we are landing, as these objectives are concise. For instance, *Perseverance*’s objectives are linked to the place where the engineering and scientific team wanted it to roam, one of those objectives being [23]: *“Determine whether an area of interest was suitable for life, and look for signs of ancient life itself.”* Obviously, this “area of interest” has been carefully selected. Thereupon, the objectives of our mission will be addressed in the following chapter, given that this chapter is merely introductory.

On the other hand, mission **requirements** are a measure of how well these objectives are achieved [24]. We will look at three different categories of these:

- Functional Requirements, that define how well the system must perform to meet its objectives.
- Constraints, which limit cost, schedule, and implementation.

Therefore, it is important that other **alternative mission** concepts are defined in case the mission defined does not meet the requirements set. For instance, the mission OCEANUS [13], conceived by NASA and JPL engineers could not meet the cost constraints they had, meaning they had to proceed with an alternative mission that could best fill some of the objectives set.

The interdisciplinarity of Space Mission Engineering

Space Mission Engineering involves working with complex systems, that is systems that comprise subsystems developed by different teams; therefore a new approach must be thought of. Earlier, Space Mission Design [25] used to approach missions in a sequential manner, meaning that every team developed their subsystem on their own and at the end all the subsystems were merged together, making this process very long as every single subsystem had to be slightly redesigned to make all the subsystems work together coherently. According to [25], this way of approaching mission design resulted 4 times slower than the current method, which is the so called “concurrent design”.

Concurrent design is based on cooperative work. Firstly, it is defined what disciplines will be needed to develop the mission, and then specialists from each field are cited in a meeting no longer than 4 hours where each specialist assesses their approach, coordinated by one person. It is important that everyone knows the other teams’ approaches in order to coordinate their subsystem, because in a complex system, every subsystem depends on every other subsystem. Concurrent design is the way mission design must be approached to reduce the time it takes to develop the whole mission. Space missions need to be [22] as fast, as good, and as cheap as possible. In sequential design, you are working slower and it is more expensive, given that more hours are spent on the project.

When designing a mission, there are two main concerns, cost and risk. These two have to be as low as possible, and to determine that, the potential adverse outcomes must be addressed, which are [24].

- We cannot do what is wanted.
- We can do it but it is not worth from what we harness of it.
- We can do it and it is useful, but the risk is too high to take it.

It is important in order to proceed that none of these outcomes are met. The mission must be plausible, it must have some utility and it must be safe.

Mission Analysis, Mission Utility and Mission Selection

In this part of mission engineering is intended to evaluate the ability of the mission to meet its fundamental objectives [26]. These three concepts become central to perform this evaluation. **Mission analysis** is the process where the performance of the mission is quantified, **mission utility** is the evaluation of the utility to the client, in the case of the agencies, the government. And finally, **mission selection** which is the process of selecting a mission to perform. However, these concepts are far more relevant in private missions, so for the sake of the length of the project we will not consider them in our mission, but they will be acknowledged as part of the process. At the end of this process, it is determined whether or not a mission should proceed.

In conclusion, three things are crucial when talking about Space Mission Engineering; 1. Setting mission objectives (and therefore its requirements), then 2. Performing the different analysis to decide if the mission should proceed, and 3. Giving a procedure to perform the mission, merging all the different fields, and covering all thinkable aspects that may involve a space mission exploration, being the mission developed in the concurrent manner.

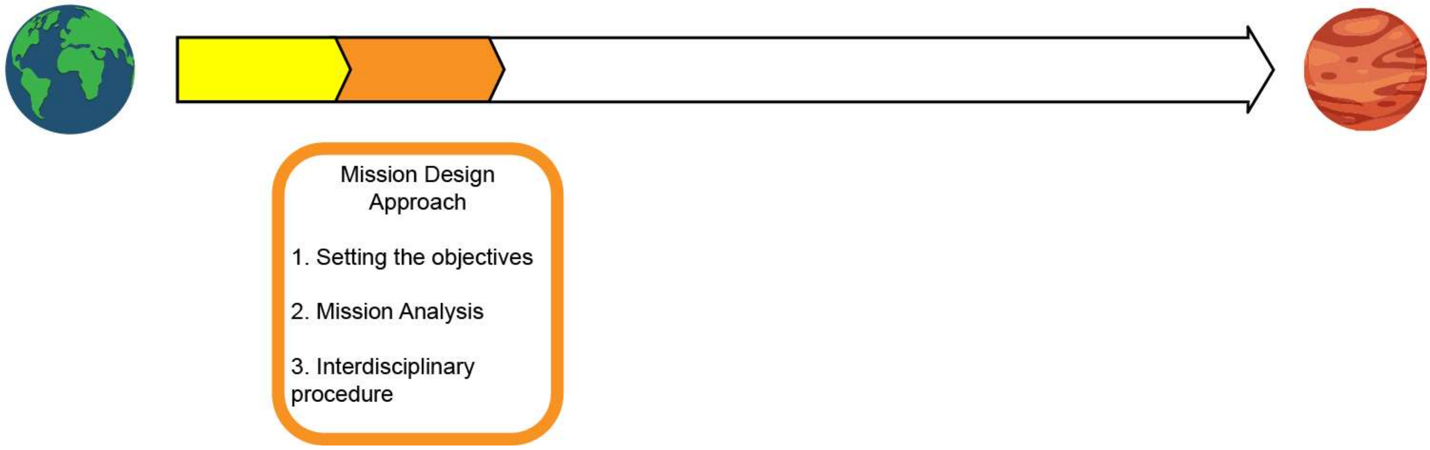

Figure 3.2 Framework updated with the new stage seen in this chapter

3.2. Procedures Onsite. Landing Spot

It is in this chapter where our own objectives for the mission are set, and where the requirements that it must fulfill are exposed. As mentioned in the previous chapter it is important to take into account the spots we are visiting in pursuance of setting the goals of the mission. Why is that? In Mars there are plenty of interesting places to visit, they range from places with potential underground deposits of water, to places that could be a potential source of methane, to places that present clear evidence of flowing liquid water in the past, etc. Thus, if for instance we wanted to discover liquid water on (or in) Mars we should go to the south pole, given that it is there where deposits of liquid water have been detected, therefore some of the objectives would be linked to finding water.

Then, it seems rather, that the landing spot is defined depending on the objectives, but throughout the project I have not said that, rather, I have said that they are linked. The reason it is said that objectives and landing spot are strictly linked and not one being wholly dependent on the other, is that there are constraints when choosing a landing spot. This is the first requirement we are seeing, which is the feasibility of the spot to proceed with the mission. One spot may be very interesting in terms of potential scientific discoveries, but may hold conditions that preclude the mission from proceeding. Continuing with the example, the discoveries on the south pole could be promising but the temperatures could hinder a human space exploration as they can reach -153ºC [27]. Thereupon, it can be seen that the landing spot may also interfere with the objectives of the mission, and therefore, having an equal relation of dependency between one another.

This has been said to understand that setting objectives is linked to choosing a landing spot. Hence, in this chapter it will be very important to address our objectives (what we want to achieve on Mars), and the different landing spots that could meet this objective, and come up with the landing spot that enables to proceed correctly with the mission, providing at the same time, good outcomes regarding our initial purpose for the mission which was to know more about how we came to be (stated in chapter 2.1).

Firstly, we must answer, what are we doing on Mars' surface? What is there to explore? How long are we staying?

3.2.1 What are we doing on Mars?

"What are we doing on Mars?" gives the purpose we have for going to Mars, a sort of "proto objectives", setting the research topics that can potentially be unveiled on Mars surface. Given that our main goal is to understand more about the origin of life and to be able to set a permanent base for humans on Mars, we have to look for what potential findings could be useful for the mission.

Discoveries such as liquid water or carbon compounds (except for CO and CO2) could lead us to learn more about how life originates [28], as liquid water is indispensable for life, and carbon compounds could be a sign of past or present microbial life, given that on Earth, they are largely produced through biological processes as well as geological processes. Also, the discovery of traces in spots where water flowed, and its further investigation could be crucial to answer our questions. Other interesting aspects to learn about Mars is understanding the cycle of volatile matter, as there are no tectonic plaques, elements should not be transferred from the surface to the mantle of Mars, as it does happen on Earth [29].

Furthermore, this feat will be an important step for humanity, as it will be the first interplanetary mission ever made, and in addition to that, we are going to set up a permanent camp to enable us to have an operating station if another mission is sent, or if there is a wish to develop a permanent human presence on Mars. The chosen spots to land must then fulfill all of these particularities.

These are some of the **requirements** our mission needs to fulfill, moreover they represent the already mentioned *"Constraints"*, limiting in this case the implementation of the mission.

Following, we will look at the different interesting spots we have considered, and their feasibility.

3.2.2 Where are we landing?

An analysis of the best landing sites must be made to choose from the different sites listed. Up until now, [30] NASA has sent their rovers based on a desire to land, work and discover. This is how they choose whether a landing spot is adequate or not, the rover must be able to land adequately, and it must be able to work on the surface. However, in our mission we are not using rovers, we are using humans, so the risk is higher and therefore the measures taken are stricter. Thus, we are going to categorize the potential sites using the following requirements that must be fulfilled:

- Potential discoveries, meaning within the site relevant discoveries could be made.
- Feasibility/Safety, the spot is feasible for what is wanted to be performed, so the mission can proceed regardless of the environment.
- Proper landing site, that is, it is safe to perform the landing maneuver with good conditions of visibility, inclination, and other factors that may affect the maneuver.

Thereafter, the landing spots identified throughout the research where the most interesting discoveries can potentially be made will be listed in Annex F.

There may be other places that could be analyzed for further exploration, but these are the ones that appear to be more promising.

To visualize where are the spots from Annex F and to better analyze them, the spots are highlighted on the Martian map (in Figure 3.3):

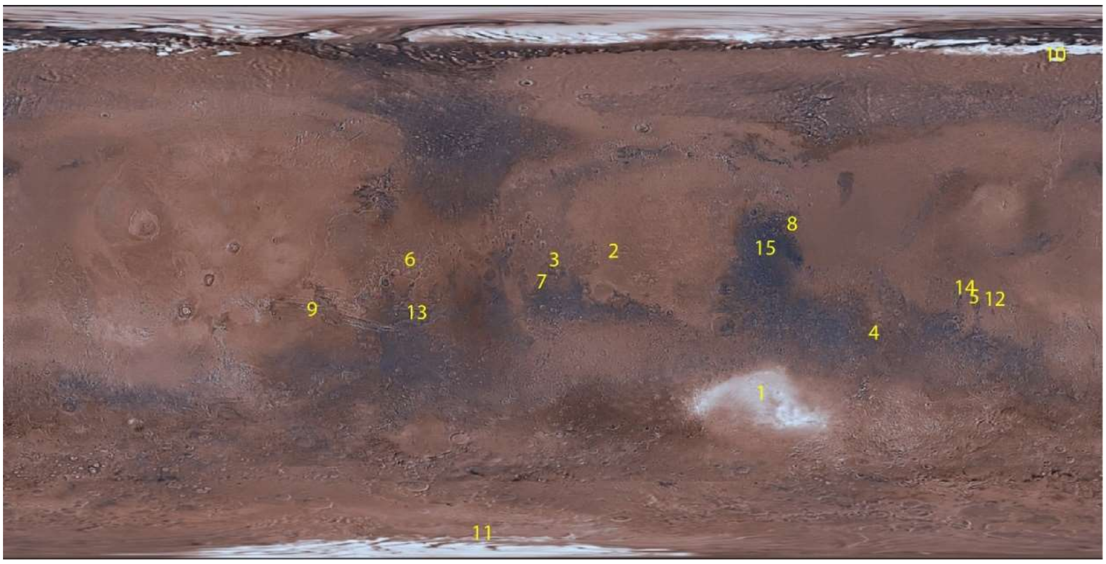

Figure 3.3. The selected spots as seen on Mars' map

In the case of *feasibility/safety* the mission must be performed by humans, so sites with extreme temperature conditions are directly ruled out. Figures 3.4 and 3.5 illustrate, the temperature at Mars' surface, and show that Mars is a cold place for humans, so going to colder places like the south pole and Korolev crater is not an option. In addition, our main source of energy will potentially be from solar power (unless we worked uniquely with a radioisotope generator, which will not be the case for now), therefore we are in need of a place where the sunlight intensity and time is maximized throughout the Martian year. It is known that the sun directly strikes more zones near the equator on Earth than on any other site throughout a whole year, on Mars, since the rotation axis is tilted as well, the same happens. Given the incline of the planet, there are zones that have less sunlight (or are even deprived from it) during periods throughout the year. Hence, we are obliged to set up the camp in zones near the equator where the sun intensity is greater.

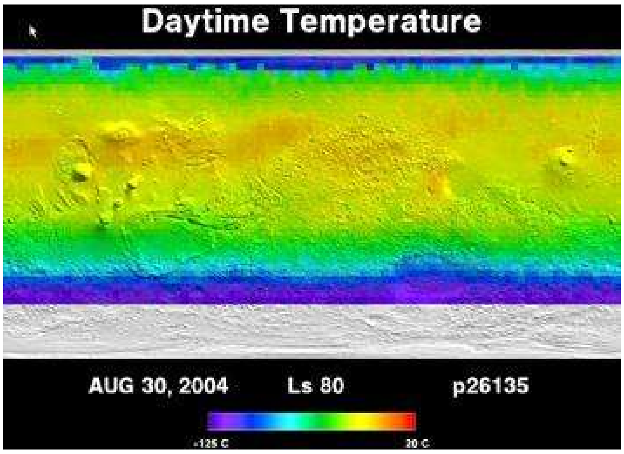

Figure 3.4 Map of Mars' daytime temperature
Source: **[Five Years of Monitoring Mars' Daytime Surface Temperatures (Animation) (nasa.gov)]**

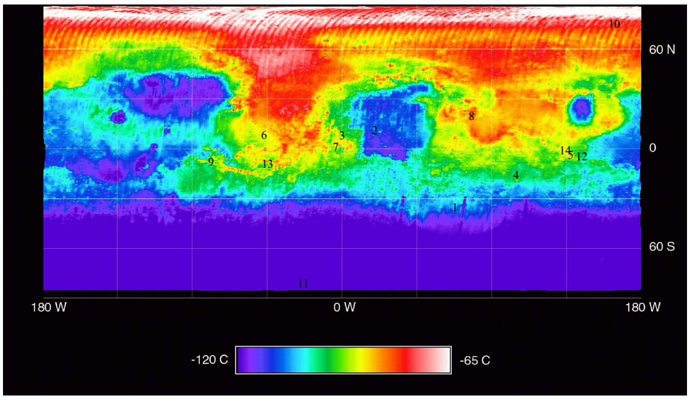

Figure 3.5 Map of Mars' nighttime temperature
Source: **[Temperature of the Martian Surface (nasa.gov)]**

Thus, the south pole, Korolev crater and Hellas Planitia can be discarded. Now, the job of finding water on Mars will be really challenging. The known places where water resides are located near the poles. However, [31] water is not a compound as unique as we have been told. Water is ultimately H_2O, two atoms of hydrogen which is the most abundant substance in the universe (74%) and oxygen is the third (1%), so its combination is not so rare. The real deal is finding liquid water because this phenomenon occurs under very particular conditions, and the only place on Mars we know of that could hold liquid water (1. Hellas Planitia), is not feasible to explore. Another site dropped is crater Guslev, which although it is located near the equator it is also in an area where at nighttime very low temperatures are reached. As you see, this constraint will condition a lot our choice.

The constraint of a *proper landing site* is thought of for performing safely the landing operation. A proper landing spot [30] needs to be:

1. It needs to be at low elevation sites, given that a method to descent to Mars is using its atmosphere to decelerate the spaceship. However, Mars' atmosphere is very thin, and therefore lower elevation sites are needed,

[32] having sufficient atmosphere to safely land the spaceship, thus avoid crashing into the surface.

Regarding this matter, the safety criterion for the elevation is 2.5 kilometers, anything higher than that is too high to safely land on. According to the topographic map in Figure 3.2.4, that would rule out site 4. Hesperia Planum, which was interesting in a geological perspective to [33] learn about the formation of volcanic areas in Mars, and overall, about Mars' formation. And it would also rule out 15. Syrtis Major, which was interesting for the past presence of water and its volcanic activity.

2. The spot needs to be at a place where the terrain is not steep and there are no sandbanks, and ultimately somewhere you can operate. For instance, setting a camp on top of a mountain will make difficult operations outside the landing spot.

Furthermore, the landing precision needs to be considered. Landing is a very precise maneuver because of the constant development that "*Entry/Descent/Landing"* engineers make, however, the maneuver is not 100% precise. Landing is performed in an elliptical radius, for instance in the case of the *Perseverance* Rover it was of 7,7 km X 6,6 km [34]. The landing site needs to be flat and with no hills or rocks in a big enough radius. A mission to 9. Valles Marineris could be done, but there is the problem of the obstacles it may have within the landing radius. It is better to start off with an area which may be clearer.

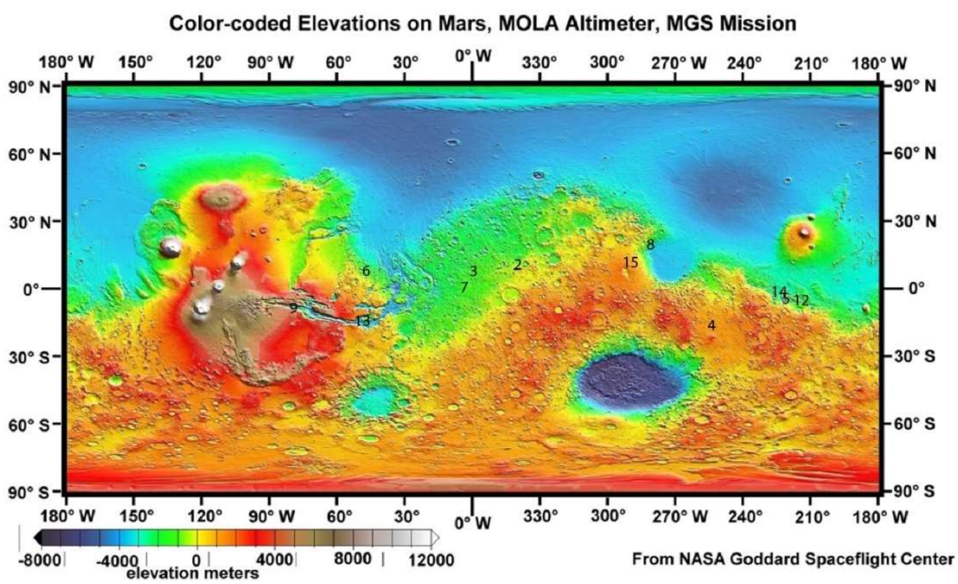

Figure 3.4 Topographic martian map with the potential landing spots represented
Source: **'Great Desert = Mars Maps 1 (usra.edu)**

Good use of probes orbiting Mars is made [35], given that they send lots information regarding the best spots there is to land, and help better plan out the landing spots for landers, vehicles and in this case, human exploration. A similar strategy was chosen by CNSA (China National Space Administration) [36] to select where the *Zhurong* rover was landing. They had to choose between two spots, Chryse Planitia and Utopia Planitia, and they made a decision based on the *Potential Discoveries* constraint.

The nine remaining locations could be promising in terms of discoveries, all seem to be feasible for our mission requirements, and we can safely land on them. However, only one spot can be selected, and the decision will have to be based on which could unveil the most interesting findings. Moreover, the selected site is the one that offers the most geodiversity [37] and enables different discoveries. The reason is that maybe a site is very promising but ends up being worthless, therefore we need other topics of interest to seek. On Earth, the geodiversity environments are the ones that are more prone to generate surroundings with biodiversity, hence complex sites are the most interesting to explore [37], this is the criteria used in the selection of exploration sites.

This decision, as it happened with the *Zhurong* mission, must be made by a scientific committee [38] in the team, it is not a one person's choice, rather a debate on why one believes that one site is better than another, and a final decision based on the option that has more backing.

On this occasion, although we are not an agency with multiple employees, with the recommendations and information given by Marina Martínez (Doctor in Meteoritics and Planetary Sciences), Jesús Martínez Frías (Doctor of Geologic Sciences and Astrobiologist, Planetary Science and meteorite expert and investigator), Antonio Pérez Verde (Engineer and Scientific disseminator) and other collaborators such as James R. Wertz, it is delivered which could be the most interesting places to explore. Their expertise in their respective fields of Astrobiology, Planetary Science and their knowledge of Mars will help best determine the best place to visit.

After the sessions held and all the information inputs, it was determined that the most interesting places are the Jezero Crater, Valles Marineris and Crater Gale. However, the one that resulted to be the most complete is Crater Gale. That is because Figure 3.3 shows that sites 12 and 14 are very close to crater Gale (which is site 5), in fact right beside it. These different spots are very close to each other, with a maximum distance between two points (Gale Crater and Aeolis Mensae) of approximately 130 km (see Figure 3.6) [39]. Although 130 km is maybe too far for safety reasons, if the intention is to set up a permanent camp, for future exploration and for developing a potential future colony, having a geologically diverse environment is very important, and 130 km is very close compared to the distance between other sites selected in Mars. In Figure 3.7 it is visible the elevation of this 130 km distance separating Gale and Aeolis Mensae, and it can be seen that there are elevations of approximately two thousand meters in about 30 km [39]. It could seem like a very big magnitude, but it represents a 6,66% slope which is high but not far off from slopes seen on Earth. Moreover, it must be considered that the gravity on Mars is three eights that of Earth [40], 3,7 m/s^2, therefore the pulling force is much smaller, hence it takes less energy for the vehicles to ide upwards. However, a first mission should not have to tackle these obstacles and should be more convenient, requiring less effort from the crew. Maybe Aeolis Mensae is not adequate (not only is it far, but the ride is a little mountainous) for an immediate mission, but it will be for later missions.

Another complication could be the elevation of the very site. Crater Gale consists of a depression with a mount in the center of it (Mount Sharp, or Aeolis Mons). Hence, there are locations in Gale that are hollow and others that are very high, that is why the area where all the exploration will be undertaken is the blue ring in Figure 3.6, which is a very large plane. Although it might look sketchy for landing operations, it is not. The site is large enough to enable landing operations, and we know that by firsthand because NASA already landed *Curiosity* here [41]. We have lots of information about this place, not only of the scientific kind, but also information about the engineering aspect of landing and operating onsite, which is a point much in favor of this spot. It is imperative that the area is as safe as possible because we are dealing with human lives this time. It is better not to be expeditive and play it safe.

Thereupon, a camp can be set up in the ring area and collect samples of the different sites. The upside of going to Gale is that in Gale there are small concentrations of magnetite (Fe_3O_4) that can be source of iron and oxygen if needed [42]. Also, the presence of past water could be a possibility according to the already mentioned information we have from the *Curiosity* rover [43]. As earlier mentioned, Aeolis Mensae is also an interesting site near our selected location that could be a potential future site to explore, where there seems to be a source of methane. That is interesting because from what we know of methane, on Earth it is largely produced through biological processes, although it could also be due to geological processes [28]. Although, our purpose is not exploiting Mars, this methane could be used as an energy source if ever needed.

Furthermore, Yellowknife Bay is accessible from crater Gale because it is within it, and it offers conditions that could be suitable for microbial life [36], which is an incredible finding. If life is found, it would be the greatest discovery in humankind's history, but if not, it would also raise a lot of questions about life and in which conditions it flourishes. Are we really special in the universe? What makes life so unique? [14]

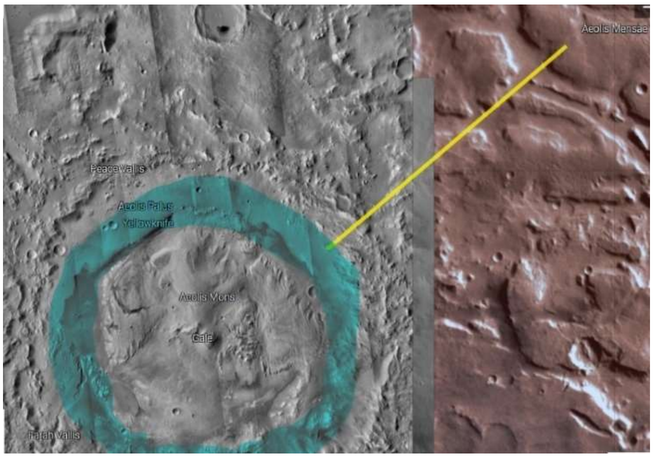

Figure 3.5 Distance between Gale crater and Aeolis Mensae. Highlighted in blue, the convenient area to explore

Source: **[Mars Trek (nasa.gov)]**

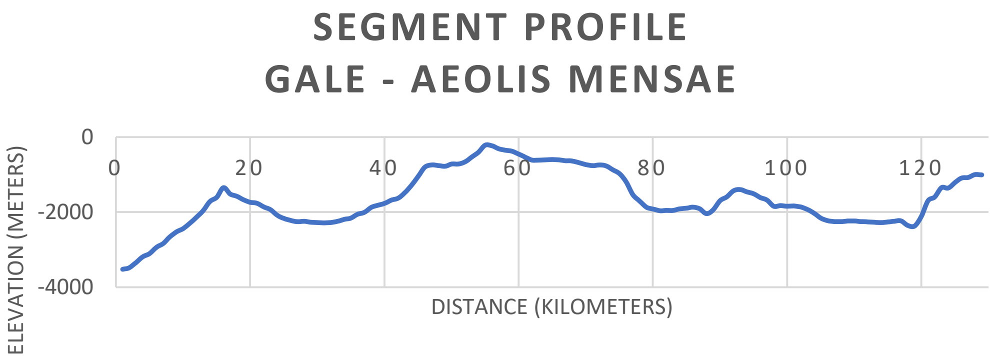

Figure 3.6 Elevation profile of the line in Figure 3.7

Our choice is settling in crater Gale, and in figure 3.9 we see where we would specifically locate it, which is quite close to where *Curiosity* is exploring right now.

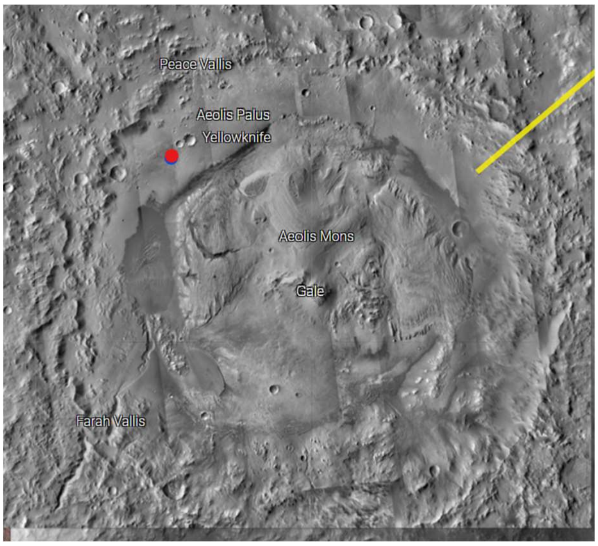

Figure 3.7 Desired landing spot in Gale marked in red

After knowing the location we are exploring, we can set the objectives according to what we can find there. For this, we will have to consider the potential discoveries from the site selected in addition to our initial purposes for exploring. The objectives of the mission can be disclosed according to the field or topic they are centered in. Therefore, the objectives set for this mission are explained below:

3.2.3 Objectives of the mission:

Planetary Science

1. <u>Learn more about Mars' interior, using seismometers.</u>

The *InSight* lander helped us better understand the interior of Mars and therefore to better know about its magnetic field and the processes inside of it. It helps us learn more about Mars' history.

The way this will be done is by setting three seismometers forming a equilateral triangle with a 100 km distance from point to point with the camp within it [38], that is, every seismometer is approximately 57,7 km from the camp.

2. Analyze Mt. Sharp's stratigraphy.

Mt. Sharp (or Aeolis Mons) is the mount in the middle of the crater, and it contains the layers of the different ages on Mars, analyzing it would tell us a lot about Martian geological history.

3. Better characterize the Geology of Mars.

Our astronauts will have to be able to read the rocks and extract the valuable information that they carry within the geologic processes that created and modified the Martian crust and interior over time [44].

Astrobiology

1. Identify signs of past or present biological life.

Yellowknife bay holds geochemical conditions that could foster the presence of microbial life. In the astrobiology area, one of the main objectives is to find biomarkers (substances that indicate a biological state), this site could be promising in this matter

2. Seek the chemical building blocks of life.

In our search for life, finding carbon compounds, hydrogen, nitrogen, oxygen, phosphorus, and sulfur is crucial to know if Mars has ever hosted life [45].

3. Identify features that may be because of biological processes.

These features must always be sought as these could later lead to discoveries in ancient Martian life or even present.

4. Analyze presence of water particles underground.

Martian temperatures seem to be too extreme for life to subsist on its surface, however, a possibility is that if there is water underground, as temperature gets warmer the closer it gets to its nucleus, maybe underground conditions are more suitable to foster life, albeit microbial.

Human Exploration

1. Suitability of humans on Mars.

This mission is crucial to understanding how humans cope with the Martian environment, whether it is bearable or not.

2. Construction of a Martian Permanent Base.

As stated earlier, this mission is a steppingstone for a much bigger feat, which is the potential colonization of Mars. This is the first step towards being an interplanetary species, therefore, it is important that this base can be used in other missions to continue the research from where it was last left. Also, if the Martian environment seems to be fine for humans and the mission is a success, forthcoming missions can explore sites like Aeolis Mensae, that is why setting up a camp is important.

3. Prepare for upcoming missions to Mars.

Everything in this mission will represent the first time it is done, so it is impossible that we have considered all things. That is why the crew must focus a lot on noting everything down, every aspect of the mission needs to be reported with the focus of improving for later missions.

4. Prove of concept of utilizing a driven rover

To cover as much terrain as possible, a rover is crucial. An objective of the mission is assessing the suitability of a driven rover like the ones used in the Apollo Missions [46], under the Martian conditions.

Mars' surface conditions

1. Provide more accurate sensing of Mars' temperatures.

We do have a knowledge of Martian temperatures, however it still could be improved. Moreover, the presence of a crew will help better understand the effects it has on humans.

2. Assessment of the effects of radiation and its severity.

As you will see in chapter 3.4, this is a serious problem of going to Mars. Due to the lack of a thicker atmosphere, a lot of radiation hits the surface. This radiation is very bad for humans, and it is an object of interest as we have to develop technology that enables us to venture outer space and other planets like Mars [45].

After the identification of several sites on Mars that would be interesting to explore, and their further evaluation of viability after having set our criteria, we have set all the objectives of the mission according to the selected site. Now we need a team to proceed with the mission.

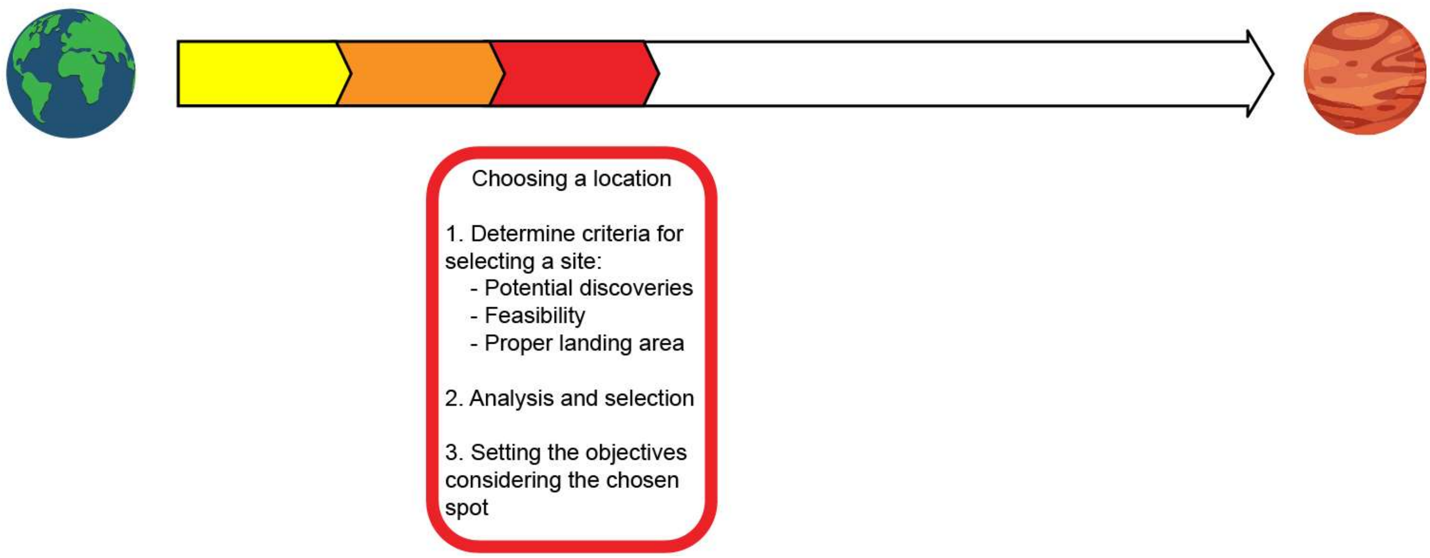

Figure 3.8 Updated framework after choosing the location to explore

3.3. Building a team

In this section the human team behind a space mission will be arranged. After all the research on the different mission teams there are in space missions, we have developed and proposed a new own model of team structure, defining which teams there is and their duties.

We will cover some of the key positions there is in Space Mission Engineering, from the mission engineers, scientists, and astronauts. Notice that these are all technical positions, there are other teams that involve important aspects like selling the mission to the population, building a story around it making it more appealing. There are also graphic design teams which are very important in NASA, as seen in Part 1, space needs to convince society about its importance. However, these teams out of the scientific/technical point of view will not be explained.

Although the different teams of a mission vary depending on the mission itself and its objectives, we will disclose them in the different groups they are organized, giving a brief and general view of the usual structure of space mission teams. We will then select what teams we need, selecting the key agents of every team. Moreover, we will be undertaking the process of selection of astronauts, identifying what the specialties of our space travelers should be, therefore identifying their main fields.

The different teams

The whole team is made up of individuals from different entities. In order of involvement in the mission progress, firstly there is the team from the very space agency undertaking the mission, then there are the contractors which are private companies, and lastly universities and international partner organizations that are entrusted with one instrument [47]. For instance, the *Centro de Astrobiología de Madrid (CAB)* is the responsible for the *MEDA* instrument on the *Perseverance* rover [48], which is a meteorological station.

When building your team, the objectives of the mission and how the mission is, are key factors that will shape the way the teams are formed. The teams only exist because they have objectives to fulfill, they have a reason to be. This reason to be, may be a certain system that is going to be used, for example.

Therefore, there are teams that will always be part of a mission no matter how it is approached, and teams that are complementary depending on the mission objectives. In this project we will differentiate both, ultimately completing our team with the complementary teams we need specifically in our mission.

Note: The following data has been developed by researching through different missions from NASA and ESA, trying to find common practices in teams over the different missions analyzed. Hence, a general composition of space mission teams has been developed, given that this information is not very accessible.

3.3.1 Common Teams

These are the teams that are found in most missions, these are essential for the correct proceeding of the mission. These teams are:

- **Agency's Supervisors:** There is always a providing entity, the one that destines their funds to launch the mission. These entities need representatives who ensure that everything is going to plan, and that the money is well spent, and it translates into fulfilling the objectives the entity sets. There are two key positions from this team, the Program Executive, and the Program Scientist. For instance, in the *Mars Reconnaissance Orbiter,* this team was from NASA's headquarters [47].

- **Project Office:** The main core of a mission exploration team is here. This team is involved in the management of the mission as a whole, ultimately executing the mission. Although all teams are very important for the success of the mission, this is the one that is most responsible for the outcome of the mission. The scope of the work of the people working in this team is larger, that is, they do not work with a particular system or procedure, rather, their work affects globally the whole mission. Some members of this team are responsible of other teams within the mission. It is in the project office where we can find the Cost Engineer [49], which is a member that is worth pointing out as it is the one that evaluates the total cost of the mission and addresses whether it is within budget or not. For instance, in [13] the team have to finally call off the mission because the cost engineer states that the mission is not within budget. Usually it is these people that are in the mission control room because the people you need to be present, is people that have an astounding knowledge of their field and have a very quick access to contacting a lot of people [49], that is usually the people responsible for each team.

  In the case of NASA's missions, these team is usually lead by the JPL, and it comprises of the Project Manager, a person in charge of Mission Operations, a Project System Engineer, and a Project Scientist to name a few [50].

- **Science Office:** This is a committee of scientists that advise among other things, topics we have already developed in this project like assessing what is best to explore, where to go next or what findings lie within a certain site. For instance, the decision of ultimately where to go made in the last chapter, which was merely based on potential findings, was assessed by this team. The science office is the team that determines what experiments should be done and the instruments that should be considered for the mission. Also, the Science Office is managed by the Project Scientist from the Project Office team. The Science Office also has Deputy Project Scientists and a Science Office Manager among others [51].

- **Project System Engineering** [51]**:** Every mission includes systems no matter its complexity, hence, every mission needs of such a team. The size of the team depends on the mission and its systems complexity. The more complex is a system (the more subsystems it has), the more people will be needed. Every subsystem has a team within Project System Engineering that is responsible for it, the more subsystems, the more teams. Therefore, this team is comprised of other teams The goal of this team is to deliver a final product that is made accordingly with other subsystems.

- **Mission Mechanics / Operations:** This team is responsible for all the processes that involve getting the spaceship from Earth's surface to Mars' surface. It is comprised mainly of engineers, in fact, it is during these processes that engineers lead the expedition and where scientists are held in a secondary position. It is they who know better how to maneuver the vehicle to get it from one spot to another. Some of these teams may be comprised of outsourced private companies, given that the vehicles used could have been built by private companies. This team is comprised of other teams that are responsible for different parts of the transfer to Mars. For instance, there is the Flight Engineering team [47], the Flight Control Team [52], the Entry/Descent/Landing operations team [13], the Trajectory Planning and Simulation team [13] [52]. Basically, every flight operation has a team or a person in charge of it.

- **Principal Investigators:** Rather than a team, this is a group of NASA collaborators. The teams within this group do not need to be correlated at all and have nothing to do with one another. The principal investigators are the fellow national and international organizations, and universities that collaborate with NASA to do research with a set of instruments. These entities are entrusted by NASA to lead the investigations regarding a particular instrument. This is where international cooperation can be seen. At the beginning of this chapter we detailed the example of cooperation between NASA and the CAB in Madrid with the *MEDA* instrument [48].

  At times, it is needed that the instruments work in parallel with one another, which results the same for the entities in charge of the different instruments, they have to work together [37].

  There are many examples of this kind of cooperation, essentially most of the analyzed missions' instruments are entrusted to other entities like ESA's *Rosetta* mission [52] and NASA's *Mars Reconnaissance Orbiter* [47] to name a few.

3.3.2 Complementary Teams

These are those teams which are not essential to perform a mission, however they become crucial depending on the scope of the mission. As mentioned earlier, the teams in mission design are strictly attached to the objectives of the mission. So, the potential teams that could exist depend on the different objectives that a mission may have.

Consequently, we will disclose only the complementary teams that will be needed for this particular mission, which are the Surface Operations team and the Astronaut Office. But before further explaining them, I want to address why they are not essential for space missions in general. At first, not all missions involve a crew, so not all missions need of an Astronauts Office. Second, if the mission is to send a probe to orbit Jupiter, there is clearly no surface operations team, however the Project Office may call for a specific Operations Team that does that if needed, because with the already mentioned Mission Mechanics / Operations team, the Principal Investigators and their use of the instruments, you should not need of any other team. A situation where another team might be needed is when there is an orbiter and a lander, which clearly have different objectives, hence may need different teams. As it can be seen, it is all about objectives and how the mission is approached. Moreover, as previously mentioned in this chapter, some other teams could be included like a Business Administration team for instance, however, we will only talk about the technical/scientifical teams needed.

- **Surface Operations:** The whole mission will be developed on Mars' surface, thus a team that plans out the different operations to be executed is needed. When operating on the surface, it is scientists who choose where to go [37], it is them who know how to better interpret the locations and the potential hidden discoveries.

  Every action taken outside on the ground by astronauts or rovers is previously designed by this team. One thing that we will further explain in chapter 3.5 is that in missions everything, absolutely everything is previously planned by teams in the agency. Nothing is arbitrary and every action is practiced over and over to minimize the error rate.

  For *Perseverance*, NASA had a very large Surface Operations team because the rover has a lot of subsystems, instruments, and accessories [51].

- **Astronaut Office** [8]**:** Composed of not only astronauts, but also of the people who train the astronauts. This team is one of the most important and definitely one of the teams where the littlest details are refined. As defined by former astronaut, Chris Hadfield, *"The debrief is a cultural staple at NASA"*. The debrief is where, after having executed a mission, astronauts and flight director make notes on the mission and how it can be improved. This process is always done, even if the mission resulted in success, there is always something that can be improved. This attention to detail is because in this team, potential failure does not result in an instrument that you cannot use, but rather a life that you can lose.

  Given that this team requires a lot of training and that it signifies one of the most important teams (if not the most important) of the mission, a whole new section is going to be written to further explain some of the intrinsic aspects of the team.

Before heading to the next section, it is displayed the mission team system designed in this project and explained in sections 3.3.1 and 3.3.2, as far as management, technical and scientific teams. Higher positions and therefore, higher responsibilities and power in decision making are on top, being the most relevant regarding decision making, the Agency's Supervisors, then the project office, and then the different teams.

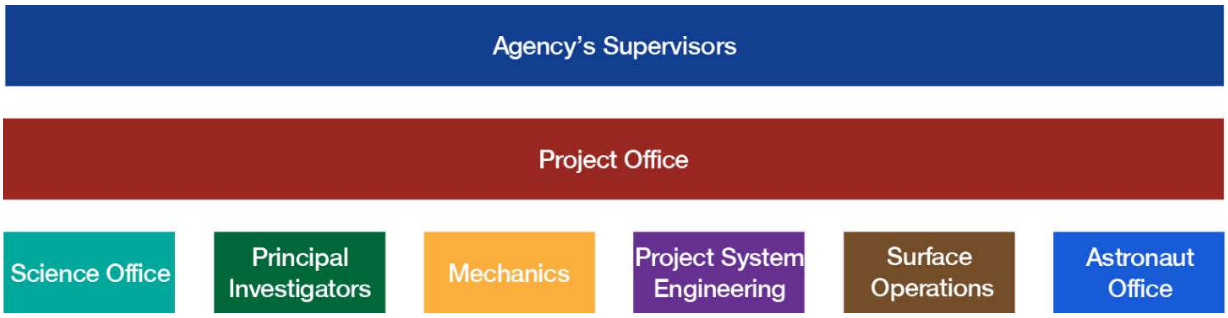

Figure 3.9 Diagram of the developed System of teams in Space Mission Design, specifically for a mission to Mars

3.3.3 Astronauts in focus

To know about astronauts, one must find a source either from an astronaut or an astronaut trainer. In this project, the memories from former astronaut Colonel Chris Hadfield and Jesús Martínez-Frías – who has been instructing at ESA's astronaut Pangea training team [37] [53] – are considered.

First, we will see how astronauts are trained, then we are going to select the astronauts that we will need for our mission.

Astronaut's preparation

According to Chris Hadfield, an astronaut is someone who is able to makes good decisions quickly, with incomplete information, when consequences really matter [54]. It is something that requires one to change its mindset [55]. He states that: *"It takes years of serious, sustained effort, because you need to build a new knowledge base, develop your physical capabilities and dramatically expand your technical skill set."* [55].

Astronauts do not become astronauts for a sole mission, they become astronauts to serve at any needed time, any required mission. This job may be one of the hardest to get, that is because not only have you got to have a set of skills that are very specific, but also because to get selected you have to pass the toughest medical test in the world [56], if you have a serious injury and if it could lead to future problems, you will not be selected [57].

Although we see astronauts as people roaming space in zero gravity, the great majority of their work is done on Earth [54]. Being an astronaut is all about preparation, and there is nothing that can prepare you more for something than training does. To be assigned to a space mission one has to train for a few years at least, and then training for a specific mission takes between 2 and 4 years and is much more intensive and rigorous than regular training, according to Hadfield. Astronauts spend most of their time training, troubleshooting for other astronauts in Hadfield's words: *"helping to work through technical problems that colleagues are experiencing on orbit and also trying to develop new tools and procedures to be used in the future."* [54]. The main objective of astronauts is to help make space exploration safer and more scientifically productive [54].

Astronauts are trained to expect every time the worst-case scenario possible, that is, anticipating problems in order to prevent them, neutralizing fear and staying focused, being assertive in their actions.

Choosing the Astronauts

To be an astronaut, one needs to have special skills. Astronauts can have very diverse backgrounds, but they must have a set of psychological qualities in common. Those allow them to respond correctly in extreme cases. However, a very important attribute for being an astronaut is communication, empathy, and all the values that help get along with other colleagues. This may not come up in a personal list of what one thinks about astronauts' qualities, however it may be the most important. Astronauts work in very little spaces with other astronauts, in a not very familiar environment, in extreme situations, often for long periods of time. Their situation naturally leads to possible misunderstandings, nerves, and getting bored of your colleagues. Hence, as Colonel Hadfield stated, one must "*get along harmoniously with colleagues, 24/7, in a confined space"*, that is the real deal. So astronauts must possess skills in leadership, teamwork and communications [58].

Adding to the already mentioned skills of being able to do the correct thing even when under extreme pressure in a calm manner and coping with your colleagues, astronauts need a set of general skills that are imperative for working in space.

General required skills

Astronauts can be pilots, biologists, engineers, scientists, to name a few, however, there is a set of skills that all will have to learn, abilities that will help them thrive on the different environments and situations they will be working on, and to have an answer to different situations.

According to Chris Hadfield, astronauts need to be able to perform basic surgery and dentistry, program a computer and rewire an electrical panel as well as taking professional-quality pictures and conducting press conference [56]. Basically, these are the additional skills that are imperative to have if you want to be an astronaut. There is no one to help fix anything so one must do it by itself. In addition, they need to be good scientists as well. For instance, NASA trains astronauts at Pavilion Lake to be geologists, not to be great geologists, but good enough ones [56]. It is important that they have an idea of how to treat nature and interpret their findings.

Now that we know the skills that all astronauts must have, we are going to select the best astronauts for our endeavor.

Astronaut selection for our mission

There are a few questions we must answer, like: what fields must our astronauts be specialists in? How many people should we bring?

To answer these questions, we need to address what we will find on Mars, and our objectives for the mission. Two very important fields stand out in the objectives, Astrobiology and Planetary Science. Therefore, we need a biologist/astrobiologist and a geologist. These may seem as a logical reasoning, however in the NASA Apollo program that from 1969 to 1972 brought a total of 12 astronauts to the lunar surface [59], but only one was a geologist [60]. This seems odd, as the only thing we are certain that we will find on the Lunar surface or on the Martian surface are rocks, thus we need someone who can better read the information that rocks contain. Hence, a **Geologist** is needed [61].

Following this logic, if we are seeking signs of past or present life, biomarkers, or biological procedures we need a person who better knows how and where to find them. A **biologist/astrobiologist** will better interpret the information and is crucial for the mission [37] [38].

Astronauts are humans too, and as seen earlier they need to have good communication and teamwork skills. This mission would last approximately 3 years at least. These people will be isolated from the world, alone on Mars, away from their families and friends. Emotionally it is challenging even for well-prepared people like astronauts, that is why a **psychologist** is said to be needed by many experts [38] [37].

Keeping up with health specialists, we will need a **medical doctor** [38] [37]**.** That is because serious injuries can happen, and it is crucial that a specialist performs the surgeries or needed operations rather than a regular astronaut. Astronauts have a general skill set but for some injuries it may not be wide enough, as they are taught to perform basic surgery.

An **engineer** is always very useful because given their preparation, they tend to be very polyvalent. Most importantly, they are the ones who know better about the systems in the spacecraft and on the base, they know how to better operate them and how to fix them in case of malfunction. Moreover, they tend to be a perfect fit for the mission specialist role, which are the ones that mount structures, solution of incidences, security checks and work on the surface, among other things [38].

To lead all the team, it is needed a person who has lots of experience in space, that has done a lot of EVAs (Extravehicular Activities; Space walks), and that basically has gone through a lot of different situations. This is the **commander** of the mission [38] [37], and usually it is the **pilot**. Although the spacecraft is very automatized, there must be a member that knows best how the vehicle works, and that is the pilot. Therefore, the team we need is comprised of:

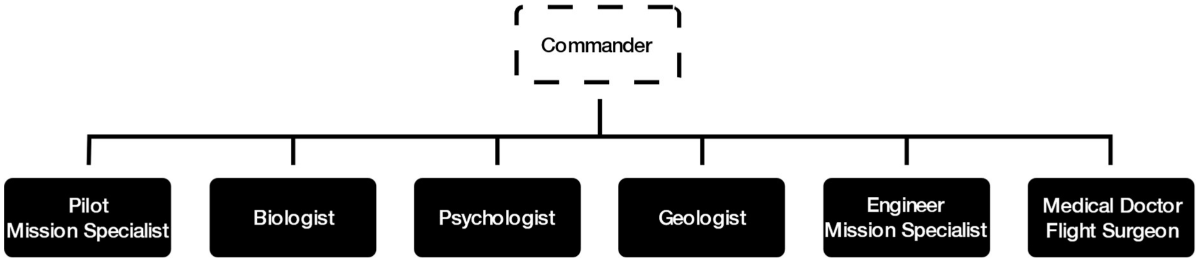

Figure 3.10 Structure of the team of astronauts

The pilot and the engineer have been selected to develop the role of Mission Specialists given that their respective fields are the ones that we think better prepare them for the job. The Medical Doctor will play the role of the Flight Surgeon given his/her experience. In addition, someone from the remaining three should be an EVA specialist, meaning he/she has a lot of experience doing space walks. Lastly, one member of the crew will have to be the Commander of the mission, although we stated that the pilots frequently play this role given their experience, it does not have to be the pilot, it could be any of the six. As we do not know which of the six astronauts would have the most experience with EVAs and to lead the mission, we cannot choose one, that is why they are not determined. It is something that depends on every astronaut.

This team of astronauts has a backup team, which is a team composed of the very same specialists and are trained just like the main team, ready to serve if anything goes wrong [46] [62].

With that, we have addressed the team we will be bringing to explore Mars surface, the next thing is defining the equipment that is going to be used.

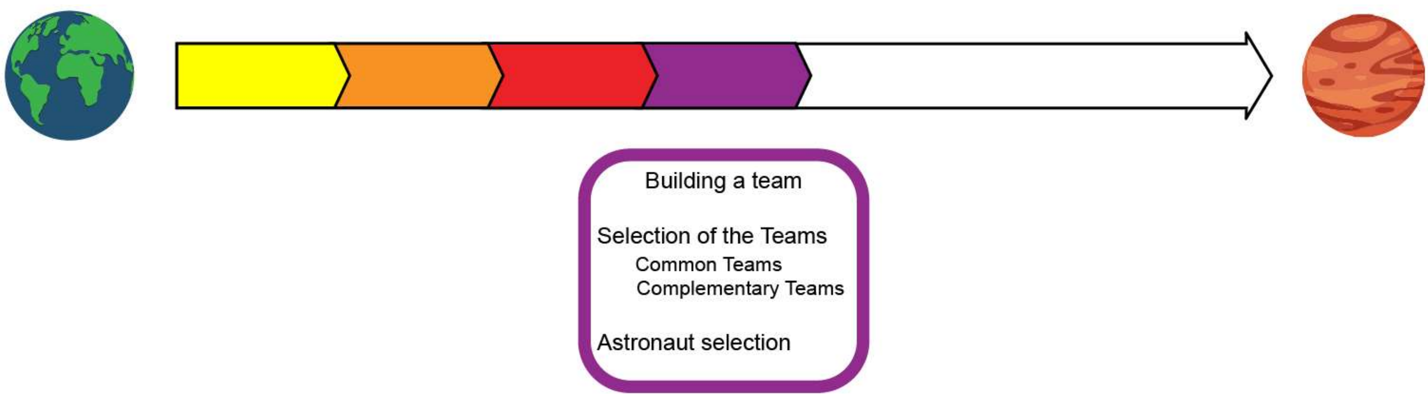

Figure 3.11 Framework after selecting the needed team

3.4. Defining the Equipment

This chapter is where we determine all the material that is going to be used in the mission. The equipment or material are all the technological assets needed, for example the mothership, spacecraft, energy sources or spacesuits among many others. Some may not be considered given that we are going to go through the most relevant systems, space missions are composed of numerous systems and subsystems and considering the project's length, it is not possible to assess all the different systems.

All along this section we will be undergoing the different situations that a Space Mission Design team must find themselves in, hence, the following topics will represent discussion topics in a space mission design team, more precisely, a system engineering team.

As mentioned in the previous chapter, when the missions are crewed, the stakes are higher than ever. Failure is not an option. An important aspect of the mission is keeping the crew alive. It is here where Life Support systems become essential.

3.4.1 Life Support Systems

The life support components are those materials that enable us, humans, to live. Traditionally they are air, water, and food [63]. Our life is supported by them, and the system that provides us with them, is called biosphere [63]. Our biosphere is planet Earth, a closed system that provides us with water, air, and food. Life Support Systems are those that try to mimic Earth, providing us with water, air, and food, but in a hostile environment. As expert in Life Support Systems, Peter Eckart states, *"the goal of Life Support Systems is to ensure the biological autonomy of man when isolated from his original biosphere"* [63]. These systems will have to be incorporated into our mothership and Martian habitat.

We must consider that we will interact with two different environments (Space and Mars), that to humans are very much the same in terms of Life Support Systems necessities, meaning we need food, air, and water, which are not to be found in those environments, at least not in the form we find them on Earth. That is why throughout this section we will explain life support systems in a broad manner that applies to both Space and Mars, however in both environments we have different conditions, thus later on a short differentiation will be made.

According to Eckart, Life Support Systems can be disclosed into five main areas [63]:

1. **Atmosphere Management**: Responsible for the control of its composition, temperature and humidity control, pressure control, atmospheric regeneration, contamination control and ventilation.

2. **Water management**: Responsible for the provision of potable and hygienic water, recovery, and processing of wastewater.

3. **Food production and storage:** Provision and, potentially, production of the food.

4. **Waste Management:** Collection, storage, and processing of human waste and trash.

5. **Crew Safety:** Fire detection and suppression, radiation shielding.

These are the systems that enable humans to live within a hostile environment. These systems are what is needed. The lack of any of them or the malfunctioning of them could endanger the life of the crew, so they are crucial. In his book, Chris Hadfield illustrates how bad the space environment is for humans, having experienced it himself, first-hand [64]: *“changes associated with long-duration space flight are definitely negative: the immune system weakens, the heart shrinks because it doesn't have to strain against gravity, eyesight tends to degrade,* […]*. The spine* […]*, and bone mass decreases as the body sheds calcium. Without gravity, we don't need muscle and bone mass to support our own weight, which is what makes life in space so much fun but also so inherently bad for the human body, long-term."*

These systems can be categorized as **non-regenerative** and **regenerative** systems, regarding whether they are recyclable or not [63]. For instance, a regenerative system is water, as it can be recovered from wastewater when showering, urine or sweat.

For such an expedition, it is indispensable advanced regenerative systems, which are crucial to economize space in the spacecraft and in the station. Thankfully we have had a great laboratory to test these systems, the International Space Station. The ISS has been very important for space exploration, as having a constant presence in space is a great advancement in space exploration, yet it does not generate such strong interest as stepping foot on the Moon. However, the ISS has contributed to many advancements, one of them being Spaceflight Life Support, and thanks to it, we know how it feels like staying in space for long periods of time isolated from Earth. As Col. Hadfield said in [64], "*the best place to study physical changes related to long-duration space flight is on the ISS itself, so that's an important focus up there.".* The ISS has supposed key improvements in life support systems. To illustrate this, in 1996 – when the ISS was not build and Space Stations where emerging technologies – water recycling systems recovered 45% of the used water [63], whereas nowadays – having the ISS hosted 269 individuals (as of June 2023) over nearly 23 years [65] – the total water recovered from the system is of 93,5% [66], which represents a massive improvement.

Apart from water regenerative systems, there are other regenerative systems. Hereby you will find the main regenerative systems enlisted below with the percentage of the mass recycled according to the different sources we have found [63] [66] [67]:

Method	Mass recycled
Wastewater recycling	93,5%
Oxygen recycling from carbon dioxide	50%
Food Production from recycled wastes	10%

Table 1 - Regenerative systems with their regenerative efficiency

Although the regenerative efficiency of the oxygen recycling system and the food production systems are not as efficient as the water recycling system, we propose an option that can complement these systems which is bio-regenerative life support systems. These are life support systems made of plants or algae that can provide oxygen and food [68], thus supporting the existing systems. Through the research made, we have chosen two bio-regenerative systems that we will use.

The first one is a whole module designed by [68] that can be encapsulated in a Falcon 9 rocket, so it is a very grounded solution. It consists of an extensible module that can be used during spaceflight and on Mars. It represents a greenhouse system that can provide from 20% up to 40% of the total food provision [68]. This translates into providing 90 kg of fresh food per month. In addition to supplying food, the plants provide benefits for atmosphere revitalization, and water recycling.

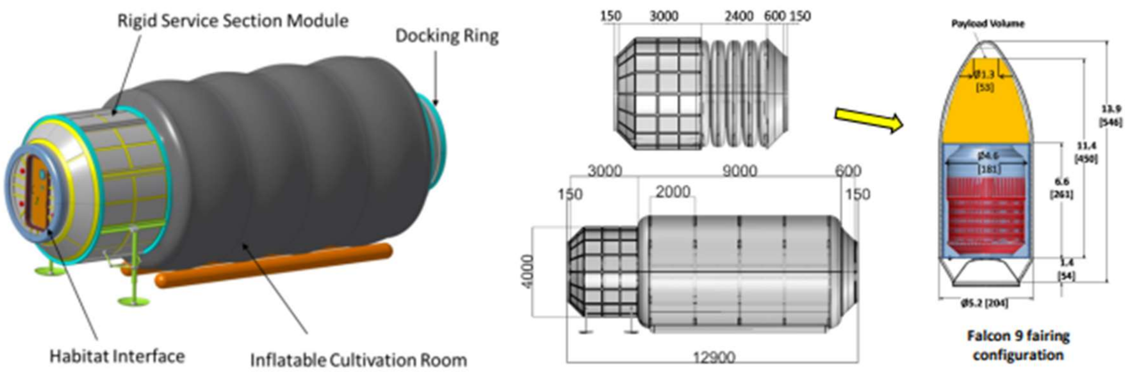

Figure 3.12 Module designed by ; Left: module extended; Center: Blueprint extended and shrunk; Right: Module Shrunk in Falcon 9 Capsule
Source: **DLR_BLSS_Roadmap_English_final_v1.0.pdf**

Another interesting compound that we could use to support oxygen regenerative systems is **bioreactors**. Bioreactors are systems that are biologically active [69]. In our case our bioreactors will contain the cyanobacteria *Chlorella Vulgaris,* used in the *BIOS-3* habitat, producing 1800 liters of oxygen daily with its 9,6 m^2 surface [70]. However, this could be further optimized with just a 20L pond full of *Chlorella Vulgaris,* it would allow to generate sufficient oxygen to supply a person daily, yet it must be well lighted [70]. This is a technology already tested in the ISS as it can be seen in [71]. In the case of oxygen, it is imperative that it is supplied correctly, because our lungs cannot take an overdose of it. The air composition on Earth is of ~21% Oxygen and ~78% Nitrogen [72], therefore we inhale these quantities. In space such conditions must stay the same way, as long as the pressure is kept the same as on Earth. Oxygen can be supplied alone only when at a pressure lower than 32000 Pa [70], given that the density of Oxygen will then be the same as in Earth's atmosphere. Hence, if we wanted to keep the pressure the same as on Earth, the resupply of Nitrogen would not be a problem because it is not processed by our body, and basically leaves the same way as it entered our body [70].

These two alternatives for growing fresh food and creating oxygen from CO_2 are going to be used in our mission, not only because they could serve a real purpose, but also because these alternatives that could enable us to explore more comfortably other worlds, must be tested and enhanced for a future potential reliable use.

Finally, life support systems cannot be developed for a mission without first considering the following constraint variables [63]:

- Crew Size
- Mission Duration
- Cabin Leakage
- Resupply Capability
- Power Availability
- Volume Availability
- Transportation Costs
- Gravity
- Contamination Sources
- In-Situ Resource Utilization

These different aspects affect how life support systems must be. For instance, with water, if the crew is larger life support systems will have to be able to supply water for more people; if the missions is longer, more water must be brought, however if there is not much space available, we will not be able to bring as much. Therefore when proposing a life support system, this constraints must not be an obstacle to use it, if they are, the life support system may not be suitable for our use case.

Now that we have seen a general view of life support systems we are going to briefly focus on the space and Martian environment, and what other aspects of life support systems can be considered. More precisely, in the following subsections we are going to address how the space suit and the Martian suit must be developed to cover all necessities we have.

Life Support Systems in Space

Throughout this section we have introduced all the different life support systems we need to keep us alive, and in space we will need to make use of every single one. Nonetheless, there are several aspects about the space environment towards which our bodies are not familiarized, and that we need to further be aware of. These are [73]:

1. Radiation – all kinds of radiation, when exposed to higher levels than in normal environments on Earth, are harmful for health [74]. Given that

space is a vacuum, we have no protection like we do on Earth thanks to the atmosphere [73].

2. Gravity – This entails one of the biggest problems of a mission to Mars. The effect of gravity has shaped the way we are, evolving in an environment where Earth's gravity is the norm. The lack of it, as Col. Hadfield's cite stated earlier, presents loss of bone mass and of muscular mass, among other things. This results in being completely inoperative once you feel gravity again. You need as much time to recover from the effects of gravity as the time you have been in space. Therefore, being the journey to Mars at least 6 months [75], it is required to do rehabilitation on Mars for another 6 months (maybe less considering the Martian gravity is lower) without medics or assistance to help you. Astronauts would arrive at Mars and would not be able to perform any operation onsite.

   Hence, something must be done about this, it is imperative that we do not go to Mars under such conditions. Thus, two options arise, firstly there is NASA's *X1 Exoskeleton,* which works by opposing resistance to movement in order to strengthen the leg muscles [76], which could be a solution to strengthen only the legs, while other parts of the body will still be affected by weightlessness. Another option would be creating a rotating module within the mothership or using a rotating spaceship, to generate a centrifugal force on the extremes as artificial gravity. Given that we see this as the most complete solution, we will develop this for our mission, however it will be further explored in the next section, *3.4.2. Vehicles Design*.

3. Atmosphere – Space is a vacuum so heat transfer in space can only be via radiation. This aspect does not entail much issue if there is air in the spacecraft, however it must be considered. In addition, the cabin must be pressurized, if not we would die in 15 seconds, and to prevent unwanted effects on materials [73].

4. Magnetic Fields – On Earth the magnetic field in the *Van Allen Belts* acts as a shield against solar wind. These belts trap the charged particles from solar wind which are very harmful to technology and to humans [73]. This radiation is more damaging to humans than medical X-rays [77].

Having seen the different harmful aspects of space, we can now address how the design of the Spacesuits to be used will be. Although it is not the goal of the mission to do space walks, spacesuits must be available in case of emergency if any system must be fixed, which often happens.

To economize space, the Martian suit and the space suit should be the same [78], nevertheless, spacesuits nowadays are bulky, and they would not be suitable for Martian exploration. Martian suits and spacesuits have different purposes and meeting them both would imply compromising the practicality of each, which is not wanted. Because of this, we are going to use a space suit and a Martian suit. In the case of the space suit, the design will resemble a lot the ones already used in the ISS, because although not all conditions are essentially the very same, they are very similar [49]. Hence, we can use the spacesuits already used in the ISS, however more attention must be given to the preparation of the suit regarding protection against solar wind radiation, because outside of the *Van Allen Belts* the radiation is far stronger. In figure 3.15 a scheme of spacesuits design is offered, to further understand all the systems within it. The Collins Aerospace new suite for the ISS for 2026 could be a perfect fit for our needed spacesuits [79], offering a less bulky, more maneuverable, and updated version of the already used spacesuits.

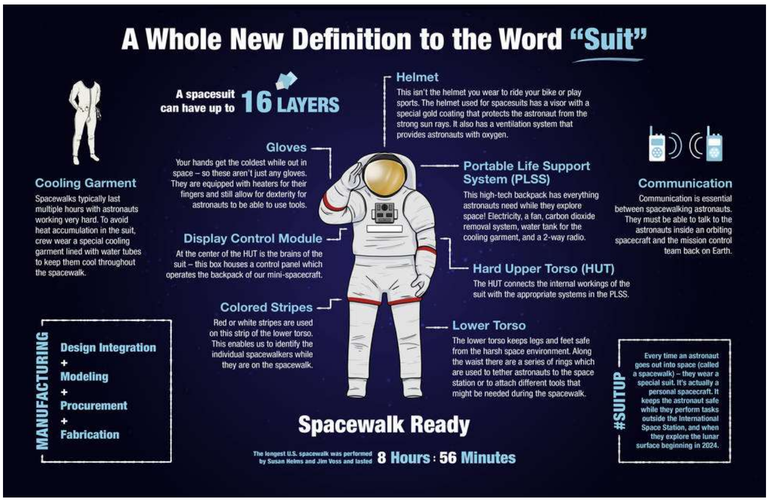

Figure 3.13 Scheme of the inner parts of spacesuits and their functionalities
Source: **Spacesuit Basics (nasa.gov)**

Life Support Systems on Mars

On Mars things get more interesting because on Mars there is lots of matter, we can find it on the surface and in the atmosphere. With it we will be able to obtain some useful resources by using life support systems that process matter. This is the first assumption that we must consider when on Mars, yet we are still in a hostile environment, it is not the vacuum of space and sometimes we can use that to our benefit. However, let us frame the aspects of Mars we must be aware of [73]:

1. Atmosphere – Mars' atmosphere is deadly to humans given that 95,3% of it is CO_2, nonetheless, this can be used in our favor as you will see later. Another aspect of the atmosphere is that it is very thin, its atmospheric pressure is about 6,6 mbar [80], whereas Earth's atmospheric pressure is 1013,25 mbar [81]. There is a significant difference that makes landing procedures, and flights on Mars more challenging.

   Mars also holds fast winds on its surface up to 288 km/h, however this is not as dangerous as it may seem [73]. Recall that atmosphere is far thinner, feeling like a sea breeze on Earth [38].

2. Temperature – As seen on section 3.2, the temperature difference on Mars is big and very extreme compared to that of Earth, ranging from -153ºC to 20ºC [82].

3. Radiation – Electromagnetic, UV and Ionizing radiation are more harmful on Mars due to the lack of a thick protective atmosphere like on Earth. Given that Mars' magnetic field is much lower than that of Earth, the free space surrounding Mars is comprised of continuous flux of solar wind radiation, which can be very harmful for humans [73].

Thereafter, the systems must consider these difficult conditions. Thus, below are discussed different systems that would help make life on Mars a little better, like MOXIE and the Martian suit.

MOXIE is a device that transforms the CO_2 into oxygen to burn fuel or to breathe, converting in 1 hour, 10 grams of oxygen (a person uses 35 grams per hour) [83]. It is not much, but this is just a test, a bigger system could supply more significant quantities of oxygen.

On the other hand, the Martian suit must consider the constraints stated above as well as providing oxygen. It is imperative that the suite allows for as much mobility as possible because astronauts will have to do lots of investigations with the suit, interacting with the environment. The already designed spacesuit for Lunar operations by Axiom would be a good fit, as it represents one of the slimmest designs there is right now [84], however further enhancements on making it even slimmer could be made, given that on Mars temperatures are not as extreme as that of the Moon.

Also, we will need equipment to perform tasks like extracting water and oxygen from the rocks [31] [70], and to drill Mars' surface to expose potential ice that could be found, like in [85], where a meteoroid impact exposed ice in the subsurface of Mars. Those resources that Mars can provide must be exploited for good.

After discussing the life support systems that must be considered and that are needed, we address in the following section the design of the vehicles used.

3.4.2 Design of the Vehicles and Flight Operations

In this section the different vehicles needed to launch the mission and to get us to Mars, including the habitat modules to use in the mothership. Mind that there will be a differentiation between the vehicles, mothership, and the rocket or spacecraft. The rocket is the vehicle that launches us to space from Earth or Mars, the mothership is the whole vehicle comprised of the different attached modules.

Furthermore, we will address how the different operations of lift-off, journey to Mars, and the landing are to be performed. As done throughout the entirety of the project we will not get into the technical details of this operations, we will evaluate them only in terms of mission design, which is addressing what is best for our needs in the mission. The technical details and calculations must be done by the mission mechanics / operations team.

Vehicles

There are mainly three vehicles to be used: a rocket launcher, a mothership, and a Mars lander module. Hereby these different vehicles' functions in our mission will be explained and a selection is going to be made.

1. **Rocket/Spacecraft –** The function of this vehicle is to propel us out of Earth's gravity, all the way to Mars. Maybe it could use some help from the mothership, but the main boosters of the whole system are in the rocket. The rocket must be powerful enough to escape Earth's gravitational field, and doing so in the most economical way, given that the whole mission will be very expensive and one way to cut down expenses is reducing launching cost, which is the greatest limiting factor to space exploration [86]. The rocket must be voluminous as we need space for six crew members, different life support systems, material needed for Mars and a rover that will be used as a means of transportation on Mars, therefore it must be a Heavy Lifter. Moreover, the rocket must be able to link up with the space station.

   The number of vehicles that fall within these criteria is quite limited. The current heavy lifters there are available are Space X's *Falcon Heavy*, NASA's *SLS* and other heavy rockets are China's Changzheng 5 and Russia's Angara Rocket as it can be seen in figure 3.16. However, considering we have Space X's *Starship*, there should be no further discussion of what launcher to use, given that it is the only rocket particularly designed to perform a mission of our caliber.

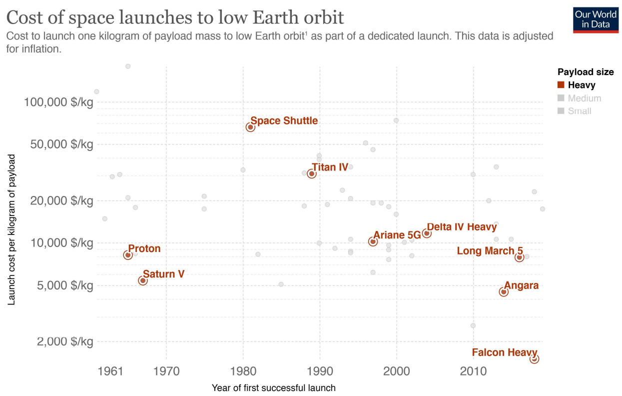

Figure 3.14 Launch cost per kg of Heavy launchers over the years
Source: **Cost of space launches to low Earth orbit (ourworldindata.org)** & **Cost for Space Launch to Low Earth Orbit- Aerospace Security Project (csis.org)**

In Part 1 we explained about the great advances this rocket involves, some of them being its low launch cost due to the materials it uses and the propellant that fuels it among other aspects. Its launch cost per kg is 10$ [87], which if not met, and for instance finally results in being 500% more than expected, it would still make it the cheapest option in the market, because nothing gets even close to that cost, it is the cheapest option by far. Space X has also made this rocket with large journeys in mind, that is why it has designed another *Starship* that would serve as a propellant tank in orbit.

Finally, *Starship* is the selected option, it has enough capacity (100 to 150 tons) [88], enough power (72 MN) [89], and has been prepared specifically for this occasion. Additionally, the spacecraft must enable modular coupling, to couple with the mothership.

2. **Mothership –** The purpose of the mothership will be to serve as a long duration habitat for astronauts on a mission to Mars, or elsewhere. Moreover, having arrived at Mars, the mothership will serve as a space station, just like the ISS to Earth, and additionally as another mean to link Mars to Earth via laser communications [90].

   It is imperative that life conditions in the mothership are adequate for human life, meaning all life supports systems must be present in the mothership. Also as mentioned earlier in section 3.4.1 *Life Support*, the mothership will have to be able to generate artificial gravity, because weightlessness has very bad outcomes for our bodies. Hence, there have been several proposals on how artificial gravity could be accomplished, however the most plausible to this day would be generating a centrifugal acceleration by using a rotating module like in figure 3.17 [91]. The module must have a ring-like shape and depending on its diameter it will have to rotate to a certain velocity to acquire the desired acceleration. Annex G discloses the calculations to know the rotation speed of the module as well as giving further information about the functioning of the module presented.

   However, this technology is still under development and has some obstacles like the cost, which would be very high considering the scale of the structure [92]. An alternative to this would be NASAs *X1 Exoskeleton*, as seen on the last chapter.

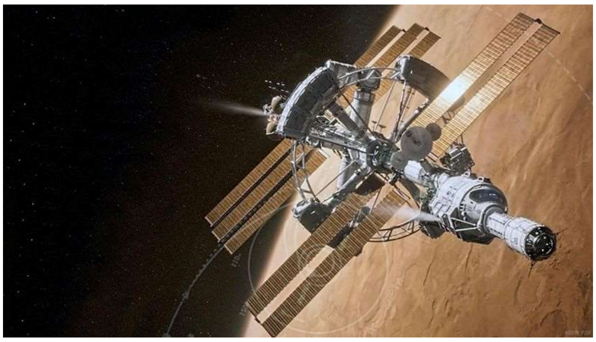

Figure 3.15 How the rotating module would look in our mothership, from the movie *The Martian*
Source: **Why We Need Artificial Gravity for Long Space Missions | HowStuffWorks**

   Every space station or in this case our mothership needs modules that hold the following systems or allow to perform the following duties [93].

- High Cargo capacity
- Propulsion & Flight Control Systems
- Docking with other vehicles
- Living quarters for astronauts
- Life Support Systems
- Bathrooms
- Exercising area
- Observation of the outside
- *Canadarm*
- Laboratories
- Equipment lock
- Crew Lock

We will explain some of these systems. The Life Support Systems include those seen in chapter 3.4.1 like oxygen generation, CO_2 removal, water recovery and air revitalization. *Canadarm* is a 17-meter robotic mechanical structure that acts like an arm to the station and helps join in modules among other tasks. Equipment and crew lock are spaces where astronauts can go for a spacewalk, it is their door to space.

These systems or capabilities are imperative to have on our mothership, and in addition to these we need to couple the Martian station modules, a rotating module, a docking system that enables docking with the *Starship* and the Bioregenerative Life Support module evaluated in 3.4.1. Below you will see in Figure 3.18, schematically how the mothership will be designed, and which modules will integrate certain systems. The dashed squared represents the mothership, thus being visible what modules are within it or attach to it. For instance, the Martian Station modules are not part of the mothership and are attached to it, and on the other hand the rotating module or the Laboratory are within the dashed squared, therefore being part of what the mothership is. Those which are attached will be deployed when arriving to Mars.

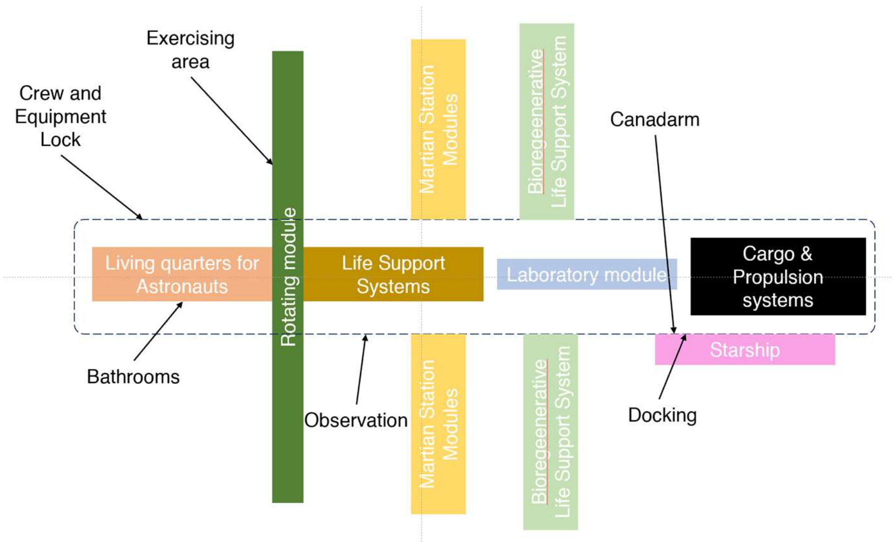

Figure 3.16 Schematics of the modules within the mothership (represented as a dashed rectangle) and the ones attached to it

Furthermore, the mothership will have attached the different modules to be used in the Martian Station, as if they were their very own. The Martian station is astronaut's habitat on Mars, and given that bringing it aboard the *Starship,* would mean that more missions would be needed to launch the whole station due to the lack of capacity, bringing it as if it was another module for the Mothership will enable us to bring more Martian station modules in a single trip. Therefore, the main purposes of the mothership are:

- Offer all the necessary Life Support Systems
- Hold the required and suitable modules
- Generate artificial gravity
- Act like a habitat on Martian orbit
- Holding the modules used for the Martian station
- Act a powerful mean for Mars to Earth communication

3. **Mars Lander Module –** As mentioned earlier, the Starship has been crafted with the goal of going to Mars among other places, so everything has been designed with that in mind. Therefore, our choice of the lander module is the Starship. A fact that further backs our choice is that it has also been entrusted by NASA to be the Moon lander module. Space X has designed the rocket with all the different operations that would entail going to Mars, including the entry, descent, and landing operations [88].

Operations

The team that oversees the operations is the Mission Mechanics / Operations team. They are the ones who address how the different stages disclosed below are performed. These stages of flight are launch, trajectory and landing to Mars.

1. **Launch –** To launch the vehicles stated above, we are going to need a lot of launches. That is why the launches are going to be split up into two parts: Launching the mothership and the *Starship* spacecraft.

   The first to be launched would be the mothership, that over the years would be assembled in LEO (Low Earth Orbit), like the ISS. Over these years the station would be tested for, especially for the rotating module, it being a novel technology. In LEO and being overwatched closely are the best circumstances at which the rotating module can be analyzed. Moreover, the Martian base habitability modules will be attached. Using the mothership as a LEO station alternative to ISS would make this mission more profitable since it is being used for different purposes and all the money would not just be invested in the Martian mission, given that further research during the assembly years can be made. This multipurpose scope of the mission will make the mission start years in advance to finally launching to Mars. If all the tests go according to plan, the mission is ready to depart for Mars.

   The *Starship* will launch when the mission is all good to go. When it departs from Earth it would be the day that the mission is finally undertaken. The *Starship* would send the astronaut team in section 3.3.3, the rover and all the other needed equipment, and would then meet the mothership in LEO to couple. From then on, after all the protocolary procedures had been done, the *Starship* attached to the mothership would be ready to head to Mars.

To launch from Mars to Earth, the same operation must be done, which is joining once again with the mothership and heading back to Earth.

2. **Trajectory –** The trajectory is designed by the Trajectory Planning & Simulation team within the Mission Mechanics / Operations team. It calculates the optimal trajectory to go to Mars for the lowest cost possible. The optimal trajectory in interplanetary transfers is defined by the *Hohmann transfer*, that is a transfer orbit between two bodies as defined in figure A.5 in Annex H [94]. This methodology is furtherly detailed in Annex H.

3. **Entry/Descent/Landing –** These are executed by the Entry/Descent/Landing team within the Mission Mechanics / Operations team. When it comes to landing to Mars, we must land the spacecraft and the Martian habitat modules. The modules would drop first and then the spacecraft with the astronauts would proceed. The mothership would not land and would stay as a space station and communications means. The landing spot at crater Gale would host the Martian station modules (that would stay on Mars forever) and the *Starship* spacecraft. For landing on Earth, the mothership would stay in Earth's orbit and only the *Starship* would return to the surface where it launched from.

3.4.3 Energy Systems

These systems are essential to power the station and the mothership, thus some of the different ways of obtaining energy will be addressed and we will choose the ones that we think are optimal for our needs. Firstly, there is the generation of electric power, essential for the correct functioning of all the systems, and then there is the attainment of propellant for the rocket if needed.

Generating Electricity

An estimation of the quantity of power needed to execute the mission must be made first to know what ways of generating electricity are best for our case.

Traditionally, the way of powering space exploration systems has been either through solar power or with the Radioisotope Thermoelectric Generators (RTG). RTGs are a great option because they deliver a lot of power and operate regardless of solar exposure, making it the ideal option for probes going to the outer solar system. Each RTG is mainly composed of a Radioisotope heat source like Plutonium-238 and a thermoelectric converter that turns the energy released in the form of heat into electricity [95] [96]. Although working with radioactive materials, RTGs have been used in numerous missions including the Apollo missions to the Moon [97].

Nuclear fission power has also been proposed as a means to obtain electricity as it is a very powerful source, and as a matter of fact, with the fission of only 1 gram we would get the energy obtained by burning 2300 litters of petrol [95]. Although, we know less about it compared to the other energy sources, it has been tested by NASA and demonstrated it is safe, yet it must be first tested on the Moon [90].

Hence, to proceed with the mission with no lack of power, we would require large solar panels to install on the camp and RTGs to be able to use some heavy consumption systems as well as for back up, in case there is not much solar exposure in a given time of the year. Nuclear fission power would potentially be used in case of success on the Moon.

Collecting propellant

Our spacecraft of choice, the *Starship* has been cautiously thought to go to Mars. One of the aspects that was considered when they designed it, was that the spacecraft would be able to be propelled with resources that can be obtained on Mars. The propellant used for *Starship* is a mix of liquid oxygen (LOX) and cooled liquid Methane (CH_4).

Oxygen can be produced from the atmosphere's CO_2 with devices like MOXIE (explained in 3.4.1), and methane can be either produced via the Sabatier reaction that would use the CO_2 of the atmosphere and the underground H_2O from Mars' that would also produce water [98].

$$CO_2 + 4H_2 \rightarrow CH_4 + H_2O$$

Another way of getting methane would be extracting it from Mars, as methane has been detected in Aeolis Mensae, however this would be for missions to come. In this first mission we would need to bring enough propellant to go back, and leave the Mars propellant production as a backup, and testing its use, but not fully relying on it for safety reasons in case we cannot meet the mass production needed.

3.4.4 The Martian Station

The design of the station must use space efficiently, that is, covering all the needs occupying a volume as low as possible, along with this in mind, cylindrical/spherical shapes are preferred to reduce expenses because they use less material to acquire the same volume than with other shapes. The station must always be designed with efficiency in mind, and it is in this brief section where we address what should be considered when designing the station. Also, the different areas that compose the station will be disclosed, this being very similar to that of the mothership.

Like the mothership, the Martian station must consider all the necessary life support systems for the recovery of air, water and waste mentioned in 3.4.1 and most importantly, providing shielding against solar radiation. Moreover, we must acknowledge that this will be the home of our astronauts for a long time, so it must be as convenient and comfortable as possible. In a module that we are going to call “Module A”, with astronaut comfort in mind, the following areas must be met in the design of Module A.

- Dormitories
- Bathrooms
- Kitchen
- Meeting area
- Rest/Leisure area

These areas are imperative and non-negotiable to give astronauts a familiar and comfortable experience, because one of the main issues that such mission could entail is psychological stability. According to [99], some psychological stressors (stimulus that affects someone negatively) are isolation, confinement, monotony, and workload, to which the crew will be exposed to. Hence it is very important to give every astronaut their own space within the possibilities. Dormitories must be separated to leave intimacy to the crew given that it is the only space where they will feel solitude. Meeting areas are important for eating meals and for gathering to organize EVAs or other procedures to be developed, basically to put different thoughts and ideas together.

Another module, called “Module B” should be dedicated to all those activities that are related to the work astronauts do on Mars. Module B should include the following areas within it:

- Workplace for each astronaut
- Laboratories

Connected to Module B we would have the Bioregenerative Life Support extendible module that we had attached to the mothership. There, further experiments in botany can be exerted and for growing food. The three modules joint would look like figure 3.19.

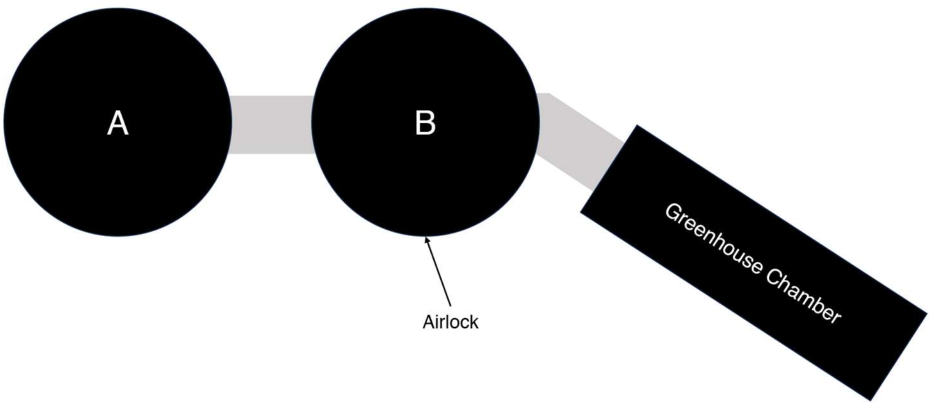

Figure 3.17 Design of the potential Martian station, as seen from the top

With this design of the Martian station, we clearly differentiate the work life from the more personal aspect of the astronaut’s life. Making this differentiation is always promoted on Earth, due to the psychological difficulties it can entail on the employees. On Mars, far away from Earth, from your family and friends, living in little compartments situated in a hostile environment that can get you killed in seconds, this psychological aspect of work and personal time is imperative to differentiate. Although astronauts are trained professionals for these kinds of situations and are on Mars to work, we must not forget they are human, and they could have difficulties adapting to the place and the overall situation. Hence a conciliation of their work life and personal life is crucial.

This has been an assessment of how some of the equipment must be chosen when designing a mission and some of the relevant choices have been evaluated, however there are many more aspects to consider.

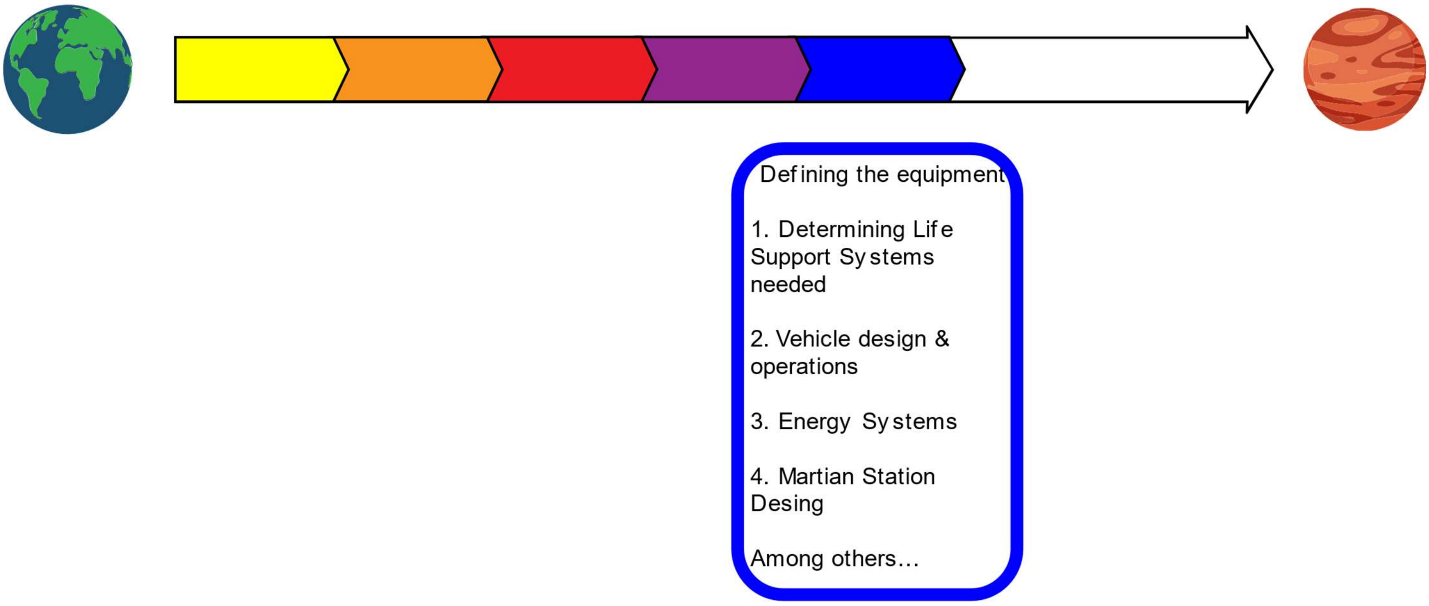

Figure 3.18 Space Mission Design framework updated with the Definition of the Equipment phase considered

3.5. Setting up Procedures & Protocols

In this short section we introduce the protocols of action and the procedures. Although it is not plausible to set protocols nor procedures ourselves because there are too many to tackle, it is very important that we mention them because they represent the "how-to" of space missions, every action is supported by them and to perform the mission it is imperative to establish a set of procedures and protocols. Thus, we are going to introduce the different topics addressed in the protocols and procedures of missions.

Firstly, something to be aware of is that space missions are all about protocols. Everything is standardized, and protocols are the standardized way of confronting problems that may arise in a mission. Therefore, the astronaut office team must set up protocols in case of adverse situations, however, these are not set up overnight, it is a long process over years of experience.

All these years of experience are transcribed into the **Flight Rules**, which is one of the most important pieces of information for astronauts. Flight Rules are a set of manuals that list, step by step, what must be done if something occurs. The Flight Rules have been compiled over years of having different problems, making mistakes, and coming up with solutions to these problems. The best way to describe them is as Col. Chris Hadfield said in [100], *"they are extremely detailed, scenario-specific standard operating procedures"*.

Before undertaking a mission, every action that is going to be made in the mission is planned in advance, especially EVAs which are planned meticulously on Earth, mimicking the very same actions to be done on the Martian surface [101]. Yet all the activities have been practiced numerous times, astronauts do run into trouble numerous times, as Col. Chris Hadfield said in [100], "*Despite all our practice runs on Earth, it often turns out that we have miscalculated or overlooked something obvious"*. Death simulations protocols are also trained rigorously, addressing how to proceed in this kind of situations, evaluating what to do with the dead body, how to tell the relatives, how to deal with media coverage of the situation so that the family does not get informed of the incident from other sources, and other issues that arise in this situations [102].

When everything is prepared to lift off, the week before launch astronauts must be in quarantine to avoid getting ill, given that on microgravity conditions the immune system does not work as effectively as it does on Earth, and the chances of infecting your colleagues are very high given that you share a small, closed space.

During the mission astronauts must perform all the activities practiced back on Earth in the same way and note down all the issues they may have encountered. The collection of all these notes on every system is written in the Mission Report [62] [46], where astronauts address the progress of every activity making observations of them, and performance results of different systems and experiments. If during the mission they encounter dangerous unwanted situations they would turn to the Flight Rules, where they would find a step-by-step solution to the problem.

There are also protocols on what to do if a discovery is made on Martian soil, for instance microbial life had been spotted, robots or humans would not be able to treat it, because they may contaminate the source. Hence a proper mission, person, device must be used to treat the source, and further investigate it [37].

Once back on Earth, the flight director, the person directly above astronauts who leads the planning and coordination of the activities done in the mission [103], makes notes on major events during the mission and gathers up in a meeting with the astronauts. In this debrief the highlights of the mission are reviewed, what new things were learned, what needs to be re-emphasized. Then every member has their say on what went wrong or what could have been handled better, system by system [100]. This is done because according to space agencies, mistakes are loose threads that can lead to worse unexpected situations, that is why it is critical to minimize them as much as possible, this is the philosophy at the astronaut office team [100].

These have been some examples that illustrate the need to set up protocols for different situations and develop procedures to know what to best do when those circumstances arise. For a space mission it is imperative to evaluate the different protocols that must be set. There must be well-defined protocols [37].

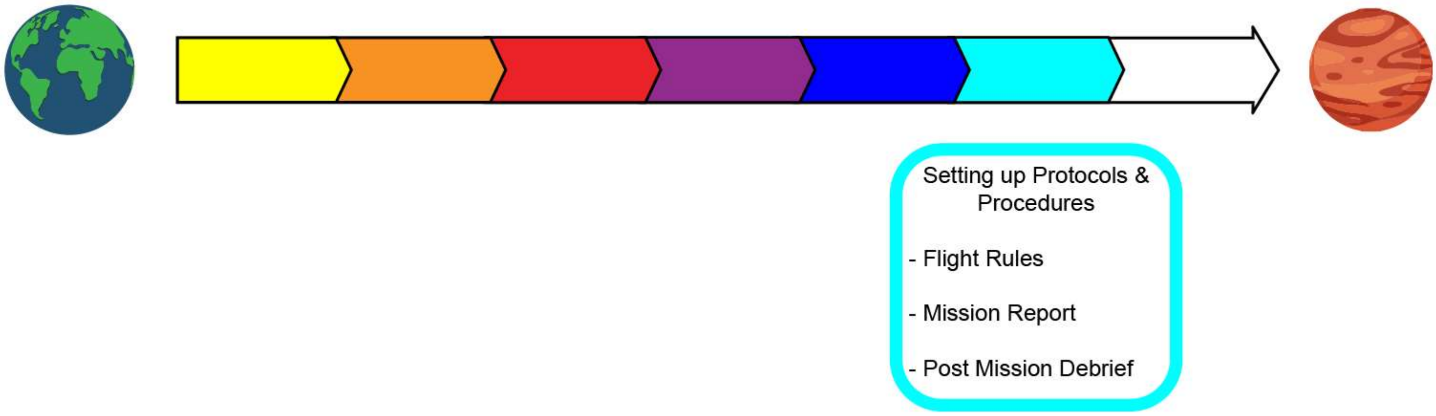

Figure 3.19 Update on the Space Mission design framework considering Protocols & Produces

3.6. Cost of the mission

After having determined how the mission will be conducted, this is the final step in our own system of space mission design, determining how much everything costs. This is the final step towards delivering the mission to the Agency headquarters and, after reviewing the mission, getting the "OK" to launch the mission. Up until now, we have planned out how we are going to proceed when developing the mission, for now it has all been a mere sketch, and it is that approval the one that could turn this design of the mission into a reality.

However, the outcome of this cost-estimating process could turn this work into nothing. If the designed mission turns out to be within the Agency's budget, we are good to go, the mission can launch; nonetheless, if it showcases an exceedance from the budget prevision, the mission must be called off or a cheaper alternative of the mission has to be proposed [13]. That is why alternative missions are also designed, to get a similar outcome in a different manner, that meets the requirements [104], especially the cost requirements.

In this short section, we will then introduce the concept of cost estimating, and the tools used to perform those estimations. We are going to see which cost estimating models and tools there are, and which are the most practical in our mission.

3.6.1 Cost estimating

Often in space, a designed mission costs as much or more than what the budget allows [105], that is because space mission teams attempt to make the most out of the mission. An ideal situation for mission engineers is that there was no budget cap. That is why using cost models or estimating how much the mission will cost is necessary, because there is a budget cap and therefore the cost of the mission must be within it.

When estimating the mission cost, the typical cost drivers are: size (in weight and information stored in software), the complexity of the materials used, availability of the technology (technology readiness levels or TRLs, which is a numerical scale from 1 to 9, to determine how mature is a particular technology to be implemented in operational space missions [22] [106]), and the schedule to develop the mission [107]. To estimate the cost of the mission, there are different cost models that can be used. Below you will find a list of the most relevant we know of:

Parametric Cost Estimation

A key concept in parametric cost estimating is the *Cost Estimating Relationships* (**CER**s), which are equations that relate the dependent variables – like labor hours or dollars – to one or more independent variables like the resources used, time or size [107]. In simpler words, they relate the cost of the mission to technical, physical, performance or size among other parameters [105]. When we use a set of CERs, we are working with a *parametric cost model* [107].

As we have seen throughout the investigation carried out to deliver this project, the parametric cost model is the most used in software tools in the main Agencies. However, others can serve as a back up to compare or better refine the estimate done.

Analogy model

It is a technique that estimates the cost of the mission considering historical data from similar missions performed [107]. Knowing the cost of missions that used a similar system or subsystems helps better address the cost of the current mission [108]. This method is very useful and is in fact all different methods are based on it.

Build-up estimate model

This technique uses discrete estimates of labor and material cost, that is, breaking down the systems into smaller low-level components for which the cost is independently analyzed, to then, aggregate all the independent costs of each subsystem into the cost of the bigger system [109]. This estimate model needs lots of very detailed data to work.

Actual cost extrapolation

Using this technique, the trends of the cost of the different systems are used to project a future cost for the same system [109]. It is similar to the analogy model, however, in this model we are using the historical data not to determine instantly the cost of the actual system, but to make a prediction for the cost of the system.

In our mission, the proposal we are making is to use the different methods to complement each other except for the "Build-up estimate model", making the final estimate as accurate as possible. Nevertheless, not only for that, but also for using the highest estimate as a reference of how high the cost can be, because in space mission design, it is common that the money spent is at least the cost estimated, if not higher. The reason we are leaving out the "Build-up estimate model" is that completing this process could be very costly in terms of people involved and labor hours spent, and to our criteria, it is not worth the potential benefit.

The different cost models introduced are relevant because cost estimating tools deal with them, so knowing them is crucial. Now that we know the different techniques to aboard the cost estimating, we are going to review the best cost estimating tools.

3.6.2 Cost estimating Tools

As previously mentioned, the preferred cost estimating model is the *parametric* model because although it is very time consuming, it provides estimate confidence based on actual data and statistical relationship [110] [107].

Cost estimating tools can be disclosed in three different categories [107]:

1. Public special purpose models – generally developed by agencies, federally funded research centers or public universities. Examples include NASA's NICM or USCM8.

2. Public general-purpose models – developed by private companies who provide software, training, and consulting services to licensed users.

3. Private special purpose models - developed by private contractors for their own use.

There are several tools, and every agency tends to use their own developed tools. Hereby we evaluate the following cost models there are in use in NASA and after analyzing them [110], we will assess how our cost estimating tool should be.

COST MODELS AND TYPE OF COST ESTIMATION		Spacecraft			
Cost Models	Estimation Type	Small Sats	Cubesats/ Microsats	Instruments	Full Mission Costs
NASA Instrument Cost Model (NICM)	Parametric			✓	
NASA Project Cost Estimating Capabilities (PCEC)	Parametric	✓			✓
PRICE True Planning	Parametric	✓		✓	
Small Spacecraft Cost Model (SSCM-19)	Parametric	✓			
NASA CubeSat Or Microsat Probabilistic Analogy Cost Tool (COMPACT)	Analogy/ (Parametric model coming soon)		✓		✓

Figure 3.20 List of the cost models available to NASA community
Source: PowerPoint Presentation (nasa.gov)

As it can be seen, all the instrument cost models use the parametric estimation type, but why is that? Analogy model is far simpler and gives us a rough order of magnitude with very little information, nevertheless the analogy model reports data that might be too broad for a specific case, and not all missions or instruments are the same. On the other hand, that is why the analogy model is very good for CubeSats, given that the design, production, and launch is far more common than other satellites, hence we have much more information. If we possess lots of different use cases, we can better determine to what mission or system our own has more similarities, and the cost may be very similar.

Nonetheless, in our particular case that is not a feasible option. How many missions have there been to Mars? None. We cannot apply the analogy method in a big scale however ww can use it to estimate the cost of isolated subsystems that may be common with other missions' subsystems. Apart from these particular cases, the Cost Estimating tool must be based on the parametric model, like in NICM, which could be a good tool to approximate the cost of the instruments [110].

To conclude, our estimating cost model must be based on the parametric model and developing an independent system should be considered, since no one has ever done the mission that we are attempting, and the resources used, and overall development of the mission will be of a caliber never seen in space history. Other estimating tools that could be used for subsystems are tools based on the analogy method like PRICE [110].

With that we will have an estimate of the cost of the mission, now we will have to analyze whether we are within the budget expected or not… If we surpassed the projected budget, we are going to look back on the mission and revise if anything can be cut-off… If we are within budget, we are going to Mars!

To finish the last section of the project, the final self-designed framework of space mission design:

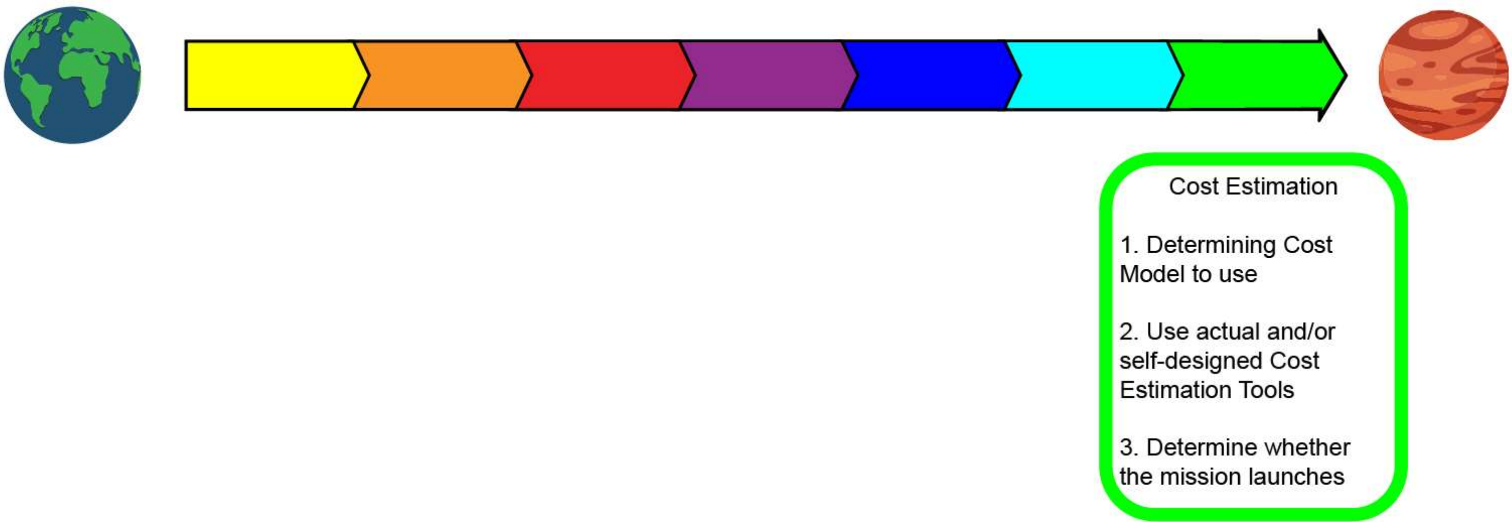

Figure 3.21 Framework of Space Mission Design updated with the last step of the process, Cost estimation

Conclusions

Throughout the work, we demonstrated that exploration is an act that should be endorsed by humanity, especially along with public administrations, as we proved that it enhances life on Earth by creating new solutions and opportunities, having provided evidence of it with several examples.

Once the decision to explore is made, the exploration process starts. Before designing the mission, the purpose of the mission is determined, whether it is for scientific, economical or safety reasons.

Considering the scientific nature of the mission at hand, a comprehensive research question must be conceived as the central focus of the mission's objectives. In this project, this question is the search for past or present life traces in other celestial bodies of the Solar System, apart from Earth. Hence, performing an investigation of the bodies that meet such conditions. Having done this research, we determine that Mars is the best option, inter alia, because we know more about it than about the other alternatives, along with the fact that we have performed many missions to Mars before. Moreover, we decide on whether a crewed mission or a robotic mission is better for the mission that we want to launch.

The Space Mission Design process can now begin. Firstly, the approach selected to design the mission must be chosen, which in this project the selected method is by setting goals and requirements, performing mission analysis, and most importantly working in a coordinated manner between the different teams. The next step is reviewing the motives of the mission to best determine the most suitable location to fulfill them, thus evaluating the exact location where the mission will settle, considering the constraints there is (extreme temperatures, sun exposure, site elevation…). Thereafter, setting the final objectives of the mission in accordance with the site selected.

Subsequently, performing the selection of the team needed to proceed with the mission, analyzing the different existing teams in similar missions, and assessing which would be the best teams to endeavor the mission. Moreover, the team of astronauts is arranged, reviewing their needed specialties, training, and the hierarchy of the team. Along with it, we evaluate the equipment that is needed in such a mission, from the life support systems to the different modules the mothership should have, the energy systems and the design of the Martian station.

The mission design process includes the evaluation of the procedures and protocols the mission involves, these being imperative for the correct functioning of it. Protocols are crucial to know how the team must proceed in any given situation, including those which are not planned.

Cost estimation is the final process and is what ultimately determines whether a mission is ready to be developed and launched. Different cost estimating tools have been suggested to provide an estimation. If the budget given is surpassed, the mission needs to be called off or an alternative design must be provided. If the mission's cost is within budget, we are ready to go.

Based on the research done in the present work, we argue that the space sector must reinforce the integral view of space missions, covering the different fields there is. Hence offering a horizontal view of space missions rather than the traditional vertical view of every discipline, addressing the interconnections there is between them.

The goal and final result of this work is to provide an early approach of how an interdisciplinary model of a space mission can be designed, and should serve as a steppingstone to further develop integrative solutions for space mission design. With that goal in mind, a unique framework has been developed covering the aspects that a mission design team should cover. The framework represents the result and the final contribution of the project (see figure 3.24), developed throughout the whole work.

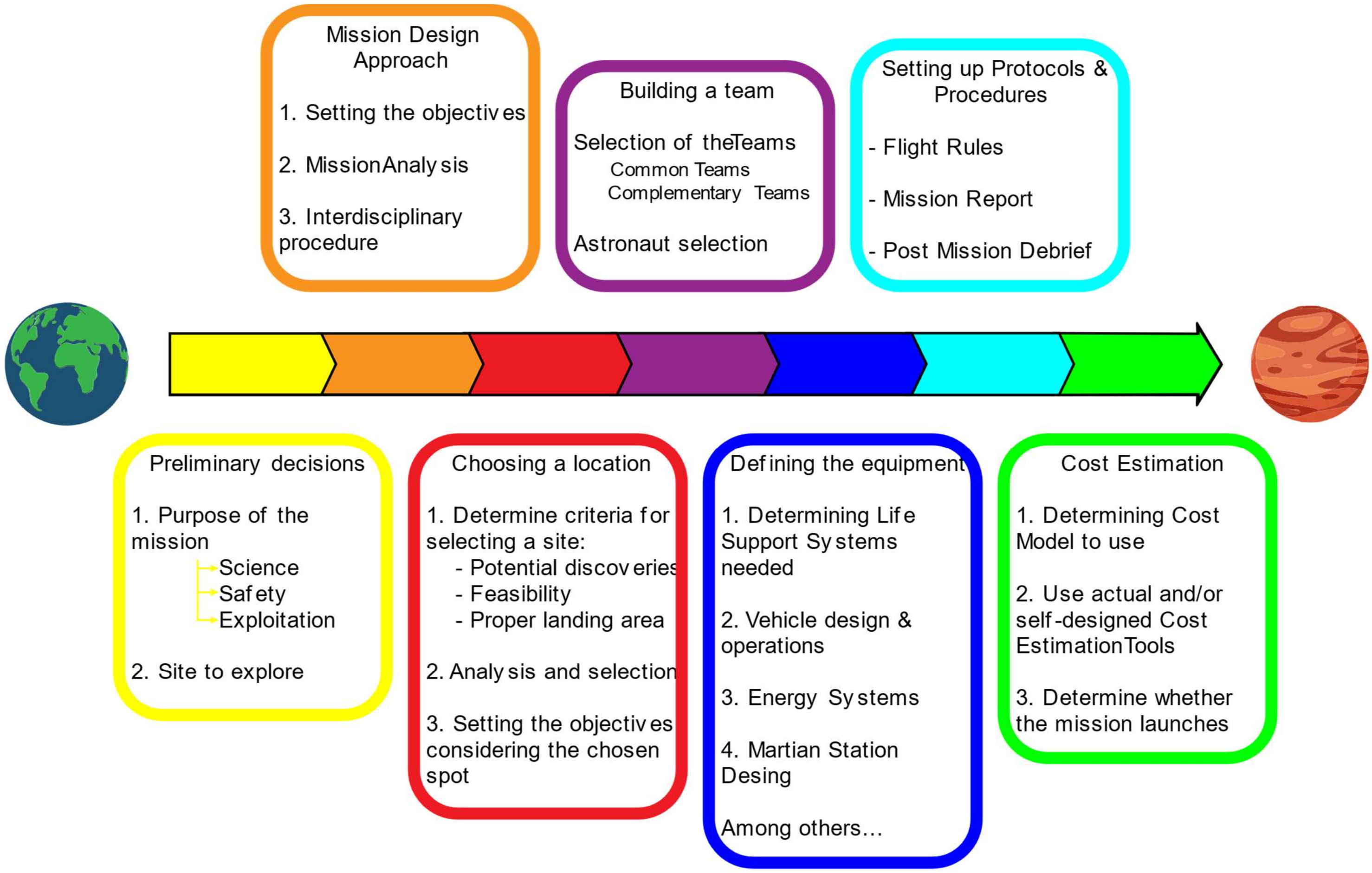

Figure 3.24 Final design of the framework of space mission design developed in this work

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ANNEXES

Title: The Reality of Space Exploration: A complete integral approach of Space Mission Design

Grade: Aerospace Systems Engineering

Author: Francesc Casanovas Gassó

Director: Hector Fornés Martínez

Date: July 7th, 2023

Annex A: Latest Advancements

Space X's reusable rockets

Space X's rockets that are now operative to launch payload into space are the *Falcon 9* and the *Falcon Heavy.* Both were massive improvements towards a cheaper launch cost and are now the choice of many companies to launch their satellites into space. In addition, the *Falcon Heavy* and the *Crew* capsule are NASA's choice to send humans to the ISS, which was the first time a private company sent humans to space. Thanks to that feat, NASA does not have to rely on Russia to launch from Earth. The launch cost per kg of *Falcon 9* and *Falcon Heavy* is 2 600 $/kg and 1 500 $/kg respectively.

The *Starship* is also made by Space X and plans to abruptly lower the cost of launching to space. It plans to be a usual means of transportation just like trains or planes, meaning its goal is to be as affordable as possible to make regular use of it, whether if it is to launch for other planets, the Moon, the ISS, or other sites on Earth. The way the company plans to achieve this is by rethinking how a rocket is made and prioritizing cost reduction. A way this is done [111] is by choosing cheaper construction materials such as stainless steel rather than aluminum, which is easier to work with and is more abrasive, hence it offers high corrosion resistance, which is a key factor for the reentry of the vehicle. Although not all are positives, working with this material has a downside, being that steel is heavier than its alternatives. Space X's chief Elon Musk has claimed that the price to launch to orbit will eventually be as low as $1 million, which considering it can hold a payload of 100 tons, would mean an astounding 10$/kg [87].

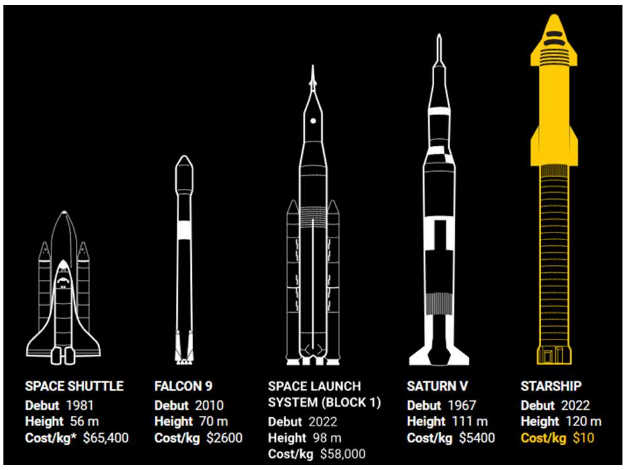

Figure A.1 Cost per kg comparison between the heavy lifters

Source: Are space scientists ready for Starship—the biggest rocket ever? | Science | AAAS

Space Launch System (SLS) & the Orion spacecraft

The SLS is the rocket that will bring the next generation of astronauts to the Moon. It has generated numerous doubts throughout the space community due to its cost, and the time when it comes, given that now expensive disposable rockets are from the past era. NASA has signed a contract to eventually use Space X's

Starship which is more powerful and costs less to perform missions to other worlds, but only as a Moon landing system. In addition, the rocket is disposable. Anyhow it is a heavy launcher to go to other worlds that will be used in all Artemis missions, but its cost is said to be approximately $4 billion [111], meaning the launch cost is 58 000 $/kg.

Other advancements

Other advancements involve alternatives to launching payload to space to make it more sustainable and economical. Some of them allow for different creative manners of launching, such as launching from a rocket from an airplane (Virgin Orbit), launching from equatorial sites with very little preparation (Equatorial Space), 3D printed rockets (Terran 1), and many more. However, the trend is to make rockets reusable and there are no big competitors for Space X, however, Jeff Bezos' Blue Origin company manufactures the *New Shepard* and the *New Glenn*, which are the counterparts of the *Falcon 9* and *Starship*.

This is proof of a tendency of the sector. The space sector needs more and cheaper launches, because there is a need to send satellites to orbit. The demand for satellite launches has drastically increased over the last 5 to 10 years (see Figure A.2), and there are companies that want to do business in the sector. In addition to this, commercial spaceflights are becoming a reality, as Richard Branson's Virgin Galactic and Blue Origin offered the first commercial spaceflights in 2021 for civils.

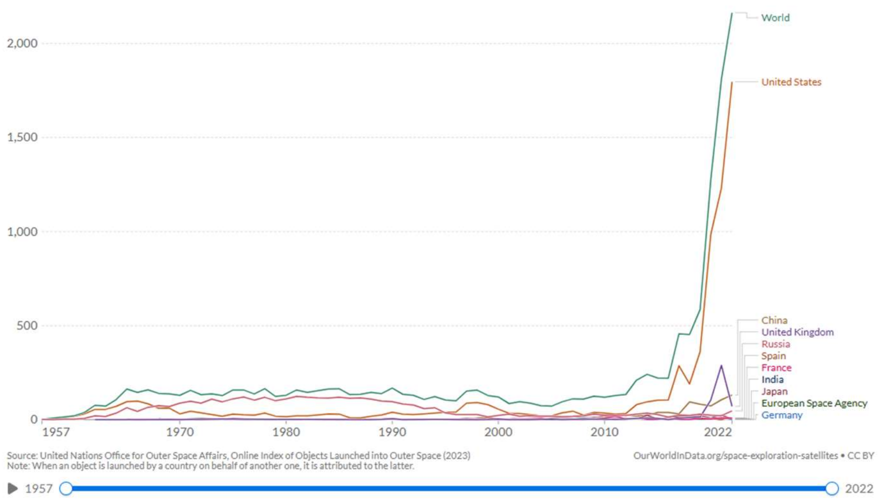

Figure A.2 Objects launched into space over the years (1957 – 2022)

Source: **Annual number of objects launched into space (ourworldindata.org)**

There are many launchers that have been significant to the industry, such as the *Soyuz*, the *Ariane* family, the *Delta* family, and many others. However, they do not represent an advancement nowadays. They used to be the old reliable way to launch payload into space, but it is very expensive to use them as they are disposable and made of expensive materials, such as aluminum or titanium [112].

Annex B: Current Boundaries in Space Exploration

We will differentiate the missions depending on if they were manned or unmanned.

Manned Missions:

- **ISS (International Space Station):** The ISS is probably the mission that represents the forefront of space exploration since it implies a constant presence of humans in space. Missions like this are the ones that make the biggest steps towards an interplanetary species, as many conclusions have been made regarding the effects the void of space has on our bodies. This will be further explained in chapter 3.4.1 *Life Support Systems*, where the takeaways from such a mission will be shown. Also, many other advancements in other fields of science are being made as the whole station itself is a laboratory.

- **Apollo missions:** To this day, the six people that touched the surface of the Moon from 1969 to 1972, are the only time a human has been to another celestial body, that is why they are mentioned, as they are at the forefront of space exploration in terms of manned missions to other celestial bodies. However, the next generation of missions to the Moon are undergone, with the goal of sending humans to the Moon in 2025 with the Artemis III expedition.

Unmanned Missions:

- **Martian rovers & probes:** The job the rovers have done so far is remarkable, and with it, we are able to determine whether is plausible or not to go to Mars, and what is there to see. The findings from these rovers are promising as some findings suggest that once there were oceans on Mars' surface, and theoretically have sensed big deposits of liquid water below the surface near Mars' poles [20], through *Mars Express*' measurements. Other probes like *InSight* showed us about Mars' geological activity as well as its weather and winds, and some developments proved flights on Mars are possible with the *Ingenuity* rover, accompanying the *Perseverance* rover. Thanks to these tough explorers, we have a better idea of how our neighbor planet looks like.

- **Solar probes** let us know about our star, investigate its core, measure the solar winds to better understand them to further develop future space travel, and especially to monitor the mass ejection from the corona and to monitor Earth's climate, these being tasks done by *DSCOVR* [12].

- **Asteroid probes** are also a matter of research, given that it is possible that someday an object from space endangers our existence or threatens a certain area of Earth. That is why missions like NASA's *DART* are so important, to deflect the trajectory of an asteroid that could represent a threat to Earth. More importantly, the research on asteroids is very interesting as they are bodies that formed very early in the formation of the solar system, and thus could contain very valuable resources [113], and their age can tell us a lot from the primitive disc that originally formed the solar system [61]. Therefore, the idea of mining asteroids is very concurrent nowadays in the space exploration sector. If this feat was to be accomplished and asteroids contained valuable resources, it could represent the exploitation of them and the very first time space would be an important economic investment. Hence the interest of many countries.

- **Giant planets' moons** have been an object of interest lately. The "gas giants", Jupiter and Saturn, and the "ice giants", Uranus and Neptune are the biggest planets in the solar system, and they hold within themselves a sort of "solar system", this meaning that they hold satellites that could be planets if they were orbiting a star. At the beginning of space exploration, when we thought of habitable worlds, we thought of planets. However, the satellites of other planets could be habitable and could be more suitable for life. These satellites hold similarities to planet's properties, like Titan (one of Saturn's moons), which has its own atmosphere; or Europa (one of Jupiter's moons) which holds an ocean of salt water. These worlds are very interesting as some like Enceladus could hold life [114], thereafter, are worth exploring. For example, ESA's *JUICE* mission (launched 14th of April 2023) plans to visit worlds like Ganymede, Calisto, and Europa.

- **Probes leaving the solar system** like *Voyager*'s missions or the *New Horizons* missions, are planned to tell us about the farther objects in the solar system, the ones we did not even know existed, Oort's Cloud, Pluto, and what there is on the outskirts of our solar system.

Annex C: How plausible and ethical is the exploitation of resources?

The idea of asteroid mining was popularized in 1997 with John Lewis' *"Mining the Sky"*. Since then, it has been an option that has gotten stronger as technology advances and as we see that Earth's supply of some elements is finite. Mineral scarcity on Earth has been an important trigger for humans to start looking to other bodies in our solar system to supply the lack of resources. This scarcity frightens humans as it could imply that our life as we know it may be in danger.

As explained earlier, asteroids represent primordial bodies formed during the first 1-5 Ma of the solar system origin (much earlier than planets) and failed to form accreted into planets [115]. Thanks to the lack of collisions within an asteroid belt, primitive asteroids (chondritic) contain valuable resources such as water, and minerals of economic interest. Other asteroids may contain mineral compounds or elements that could be used as fuel, allowing to use them as "future fuel stations" as stated in [115]. Hence, the interest of investing in them.

However, there are 3 main factors that must be considered: Its feasibility, its ethics and the role politics will play in it.
When talking about feasibility, it is important to mention an interesting type of asteroids, the *NEAs (Near Earth Asteroids)*. We do not have to go to the asteroid belt between Mars and Jupiter. There are asteroids "floating" alone in space, or better said, roaming in space, that is, they do not have a regular trajectory like other asteroids have. Hence, sometimes they fly-by near our planet and, by deflecting its trajectory we could make them orbit earth. Another option is going to the asteroid belt, but that makes the process more complicated.
Politically speaking it is important that space law is reviewed or re-written all over, as the laws are not very clear about the utilization or the ownership of outer space resources [115].

Because of this matter, a debate has sparked on whether or not this practice is ethical, which is still a matter of discussion in the present times. The fact that international laws are not clear about the rights of exploitation is very dangerous as this could mean that the ones who get first have the right to exploit it however they want. A bad practice could lead to further inequality on Earth [116], given that the only agents that have the power to accomplish these feats are the most powerful. The debate does not end here, as some scientists also have concerns about exploiting other bodies, altering nature in favor of the human species, destroying what we find in our way. Some ethical concerns are (i) "the preservation of environments on planetary bodies", the (ii) "long-term environmental impacts of resource extraction on planetary bodies", and the (iii) "short-term impact of largely unrestrained resource extraction on wealth inequality" [116].

The present study suggests that this kind of endeavor is feasible yet very complicated. It is true that it is not ideal to be manipulating objects in our solar system, but if it is ever done, it has to be for necessity. We must value life, not only ours, but life on Earth. Therefore, it could be more unethical to exploit Earth rather than a lifeless (if so) object in the universe. Then, why extract resources

all in all? As mentioned in Part 1, humanity will be obliged to someday be interplanetary, and to preserve our species advancements need to happen. Maybe there is no real need now, but there may be one day when that need is real, and when the ethics on whether it is right or wrong to exploit other bodies will not be as relevant as the need to preserve our species.
To this end, it is important that we understand space as a conquest of humanity, not a country or a company, but as a species. Thus, it is important that we make such relevant decisions bearing this in mind, meaning that space must be for all and for the benefit of all.

Verdict

Focusing on the scientific approach of a space exploration mission, the goal is to find the answer to questions that have never been resolved before. Questions like whether we are alone in this universe, about life and whether it is as unique as it seems, or the quest for liquid water in the universe. Answering these questions will let us know more about our universe, about our existence and how it came to be. As mentioned in Part 1, seeking for these answers is part of our nature. It is this innate quality of humans that has made humans prosper.

Annex D: Speed and time in space

It would be fantastic to explore other bodies outside of our solar system. In other solar systems there are planets with Earth-like conditions that could hold life, and maybe even advanced life. Nevertheless, that is not possible with the means we have nowadays. Regarding this matter, time is our biggest enemy. We are restricted by the time it gets to go to other places in outer space, as the distances in space are enormous and the vehicles' speed that we possess is currently insufficient. To put that in perspective we will use the fastest moving object humans have made as of May 2023, the *Parker Solar Probe* [117], which takes advantage of the Sun's gravitational pull to speed up. Its current speed is approximately 585 000 km/h which is 163 km/s. It is so quick that to illustrate this, it would take us from Barcelona to Paris (840 km in a straight line) in just 5 seconds. That is just 0,0543% of the speed of light, which in terms of "cosmic speed" is ridiculously slow. How fast an object moves is relative to what we are comparing it to. Is a land turtle fast (4,8 km/h)? To us they may be slow, but to ants (3,1 km/h) which are tiny, turtles are quite fast. This illustrates that speed is relative to what we compare it to.

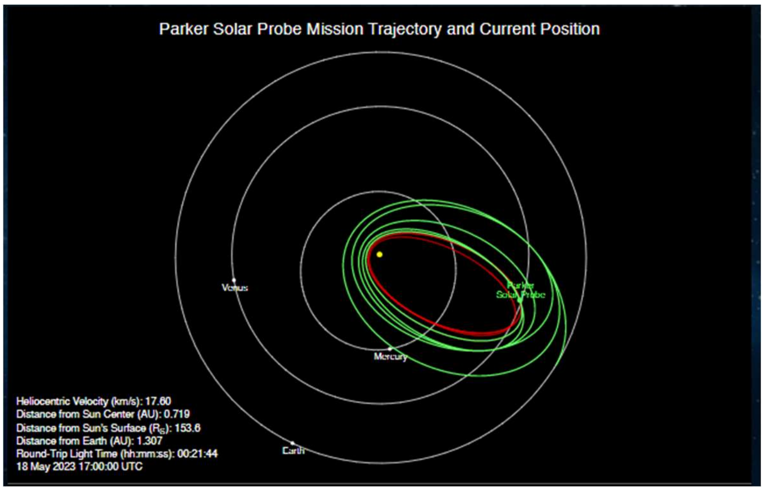

Figure A.3. Parker Solar Probe trajectory around the Sun in green

Source: **Parker Solar Probe: The Mission (jhuapl.edu)**

In this case, given that distances in space are so immense, they are measured in the time it would take us to cover them going at the speed of light. That said, the distance to the closest star to the Sun, Proxima Centauri, is approximately 4,25 light years away. That means that if we wanted to visit it, it would take us 7826,89 years. And when the *Parker Solar Probe* reaches its maximum velocity at the perihelion (see Figure A.3) of its orbit around the Sun, it will speed up approximately to 700 000 km/h which is 194 km/s, corresponding to 0,0648% of the speed of light. With this velocity, and bear in mind that this will be the fastest object we will have ever made, the probe would reach Proxima Centauri in about 6558,64 years. It is a simple calculation (Equation 1), where d is the distance between the Sun and Proxima Centauri and t is the time it takes to get there.

$$v = \frac{d}{t} \ ; \ 3 \cdot 10^8 [{}^{m}/_{s}] = \frac{d}{4,25\ [years]} \ \rightarrow$$
$$\rightarrow \ d = \ 3 \cdot 10^8 [s] \cdot 4{,}25 \cdot 365 \cdot 24 \cdot 60 \cdot 60\ [s] = \ 4{,}02084 \cdot 10^{16}\ [m]$$

$$t = \frac{d}{v} \ ; \ t = \frac{4{,}02084 \cdot 10^{16} [m]}{3 \cdot 10^8 \cdot \frac{0{,}0648}{100} \cdot (365 \cdot 24 \cdot 60 \cdot 60)\ [m/year]} = \ 6\ 558,64\ years$$

Equation 1

The example above showcases the magnitude of distances in space, and it is something that will limit our options. Thus, our options are enclosed in our Solar system and the places we can explore are going to be within it. In addition to this, if we wanted to perform a crewed mission, we would have to further consider the duration of the journey, because as we will see in *3.4.1 Life Support Systems*, the longer the stay in space is, the worse. So going to Neptune (12 years), Uranus (9 years) and Saturn (3 years) are endeavors difficult to undertake with a crew given the current vehicle capabilities we have. If we want to explore these worlds it is more cautious to use a probe, in accordance with the missions performed up to date.

Annex E: Discussion and review of robotic and crewed missions

Robotic Missions

Throughout history, robotic missions have been performed for two reasons. One is safety and reconnaissance, and the other is feasibility. Therefore, the decision of whether to use a robot or a human to perform a mission is strictly linked with these two factors. As suggested earlier, there are missions that are not feasible for humans, like *Parker Solar Probe*'s mission or the *New Horizon*'s mission to name a few.

For such missions rovers are very useful. They enable us to explore places that we would then not be able to explore because of the conditions of such expedition. We can explore the confines of the solar system only having to worry about the rover's state and battery life. There is nothing at risk apart from the money spent on the mission and the reputation of the agency undertaking the mission, which is not little, but is much less than risking a human life. For this reason safety and reconnaissance have been a use of probes throughout history. They helped us examine the areas we wanted to explore, to know more about them without risking lives in the process.

When launching a crewed mission, the stakes are higher than ever before because the cost of a potential failure, would translate into the death of the crew performing it. That is why in the first instance, robotic missions were proposed. The first robotic space mission, *Sputnik 1,* launched on the 4th of October 1957, becoming the first artificial satellite. It served as proof that those estimates that the engineers had done, were possible; but to first try it with humans would have been foolish, as it would have been a risk too severe to take. The flight that *Sputnik 1* did was crucial to understand more about the physics of launch and of the space environment and would become a steppingstone to bring the first human to space, Yuri Gagarin in the *Vostok 1* the 12th of April of 1961. That has been done throughout the history of space exploration every time a new mission has been proposed. The first step of the program is to send a robotic mission that does surveillance, to know the environment the crew will be facing and all the challenges they may encounter.

In the case of Mars, rovers have served to understand more about the surface of Mars and to know if it is worthwhile to go to explore its surface with a crewed mission. For now, given that the results sent from the rovers have been so promising and the conditions onsite seem to be acceptable for human presence, we know that we can go to Mars' surface. It was then that the job done by the probes was crucial, because the *Venera 4* and the *Mariner 5,* both launched in 1967, [118] were able to demonstrate that the reality was very far from the expectation. Venus was too inhospitable to hold life. This illustrates the success in the usage of probes to understand worlds and to know if they hold conditions to accept human lives. All the probes exploring the confines of the solar system, the Sun, Jupiter, Saturn and those places with inhabitable conditions illustrate on the other hand, the probes that serve a purpose as explorers in extreme conditions.

Crewed Missions

To perform these missions, two things should be guaranteed. First, a probe must have done its job serving as a tester to understand the conditions of the environment. If the results are positive, then the second thing that must be guaranteed is that the place is worth exploring. If one of those is not met, then the mission shall not be proceeded with a human crew.

The job probes do, is therefore, crucial. A place is worth exploring considering the time and energy it would take to get there, the danger of the expedition, the potential discoveries, and the cost of the mission.

Up until now, rovers are doing a great job at what they were meant to do, but that does not exclude the fact that their mobility is very limited. The reason for this is because to move a rover which is another planet, the communications take time to travel from the rover to Earth, and this time has to be considered because if there is an emergency and the rover must be stopped, the rover may have already crashed by the time it has received the order. To avoid that, rovers move very slow, therefore if a danger is encountered, the operators have time to react. For instance, the latest NASA rover, *Perseverance,* moves at a maximum speed in flat surface of 4,2 cm/s [23]. This factor is very limiting when exploring because you have to choose wisely where you want to explore, given that you will not have much mobility.

The rover that has travelled the largest distance ever is *Opportunity*, which was able to travel a total distance of 45,16 km [119], over the span of 15 earth years. To illustrate the pettiness of this distance, the astronauts in Apollo 17 mission that stayed barely 3 days on the Moon, travelled with the *Lunar Roving Vehicle* a total of 36 km [46], yet this rovers served as testers of the usage of driven rovers in the lunar surface and could not move away from the base camp further than 9,6 km.

However, human spaceflight missions are the ones that become more costly by a vast difference. According to [120], the typical mission cost of Human spaceflight is *"$2 billion – $200 billion*)

In addition, as mentioned in Part 1, it is important that we start traveling the cosmos because if we want to assure that our existence will endure, we will someday have to move out from Earth, establish camps in other worlds, becoming interplanetary species. Establishing a permanent base in Mars is advancing towards this interplanetary future that inevitably lies ahead, and that needs of humans to undertake this mission.

Annex F: Identified landing spots in Mars

	Sites	Potential Discoveries	Feasibility	Proper landing site
1	Hellas Planitia	Lowest point on Mars. It is the only place where liquid water could occur on Mars' surface. [31]	Not feasible	-
2	Guslev Crater	Guslev Crater and Meridiani Planum had similar phosphorus concentrations which can only happen if they once shared a common sea [43]	Not feasible	
3	Meridiani Planum	Opportunity found hematite concentrations in the form of spherical tiny balls. This evidence proofs that once water flowed there. [43] [42] [36]		
4	Hesperia Planum	This is where most fluvial surface landforms are mostly distributed.	-	Not very adequate
5	Gale Crater	*Curiosity* rover once found here a lot of nitrate sediments, which means the crater was once full of water. [43] Concentrations of 3% and 8% of magnetite where found [42]. Which is relevant because it is formed in oxidizing environment, and water is oxidizing. [29] There is a clear erosion on the rocks that could be a sign of past fluvial activity. [19] In the center of the crater, there is Mount Sharp, which has a lot of the past Martian stratum. [38] [121]		
6	Shalbatana Vallis	First evidence of a Martian shoreline of an ancient lake of 210 km^2 and a depth of 460 m. In addition, the *Mars Reconnaissance Orbiter* sensed that this ancient lake contains copper. [42]		
7	Endurance Crater	Jarosite was found in here, which on Earth its formation involves acidic waters. [19] In fact, the discovery of Jarosite is very promising because it is hydrated, that is an indication of past water on Mars. It also could indicate the present of potasium		
8	Jezero Crater	There have been spotted sediments that suggest that there could have been conditions to hold at least microbial life. Earlier in Mars' history, it was a lake. [19] Furthermore, *Perseverance* rover has taken pictures of what seems like a river that flowed into Jezero Crater. [122] [123]		
9	Valles Marineris	FREND instrument detected water here, it has potential for a future mission of space exploration [19] [124] It also has lava tunnels that could result useful as camp base [38]	-	Not very adequate
10	Korolev Crater	It contains 1 200 km^3 of water in the form of ice [35]	Not feasible	-
11	South Pole	Beneath its surface there are water deposits. [35]	Not feasible	-

12	Aeolis Mensae	Potential source of methane in Mars [28]		
13	Columbia Hills	Goethite was found here by Spirit, which is only seen in water environments [36]		
14	Yellowknife Bay	There have been found geochemical conditions that would allow for microbial life to live. [36]		
15	Syrtis Major	In the past it had water and volcanic activity; it is a good combination to augment the potential of habitability of the site [38]	-	Not very adequate

Annex G: Calculations of the rotating speed the module must have

In figure A.4 it can be seen the different accelerations acquired depending on the angular velocity of the rotating module. This is very useful for a mission to Mars because the acceleration could be varied according to where we are heading to better prepare for the conditions of the destination [38]. For instance, if we are going from Mars back to Earth, we can gradually increase the gravity from Mars' 3,7 m/s^2 to Earth's 9,81 m/s^2 during the six months of the journey. This will enhance astronauts' conditions when returning to Earth and reduce recovery time.

The angular velocity at which the module must rotate can be calculated with simple mathematics and basic knowledge in physics (Equation 2), given that we must match gravity's acceleration to the centripetal acceleration; if for instance we developed a rotating module of 20 meters of diameter, the calculation of the angular velocity would be 9 rpm.

$$a_n = g = 9{,}81\, m/s^2$$
$$a_n = \omega^2 \cdot r \; ; \; a_n = \omega^2 \cdot 10\, m = 9{,}81\; m/s^2 \rightarrow \omega = \sqrt{0{,}981} = 0{,}99\, rad/s$$
$$\omega = 9\, rpm$$

Equation 2

Thus, for Mars' gravity the angular velocity for a module of this proportions should be 5,81 rpm.

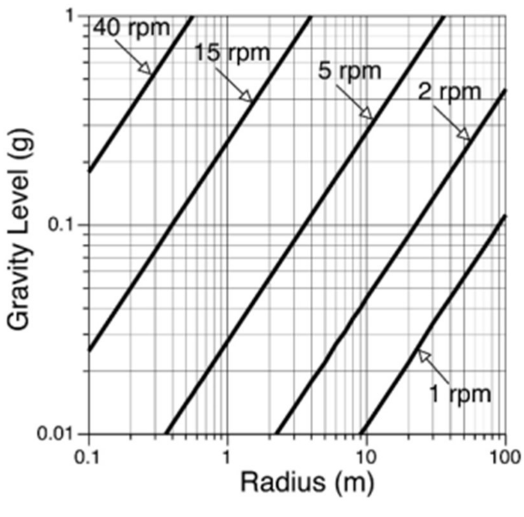

Figure A.4 Gravity generated in G's depending on different angular velocities and the radius of rotation of the ring **[91]**

Annex H: Selected Hohmann Transfer Orbit to Mars

The time it takes to get to Mars strictly depends on the relative position of Mars and Earth at the time of launch, that is why the “launch windows” are so important to determine what time is best to go to Mars, but it is approximately 7-8 months. Moreover, there are two different ways to go to and return from Mars. There is the conjunction type and the opposition type (see in figure A.6). The first takes 1005 days in total with 558 spent on Mars, and the second takes 560 days with only 40 days spent on Mars [125]. At first our aim would be to perform the conjunction type of trajectory because it allows for further exploration and for setting the camp. Nevertheless, the opposition type may be used in case of constraints in cost of the mission or time constraints. Thus, the mission duration would be of about two and a half years.

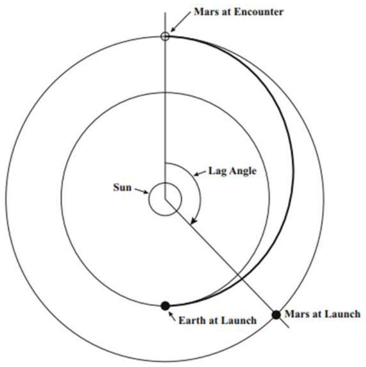

Figure A.5 Hohmann Transfer orbit between Earth and Mars **[94]**

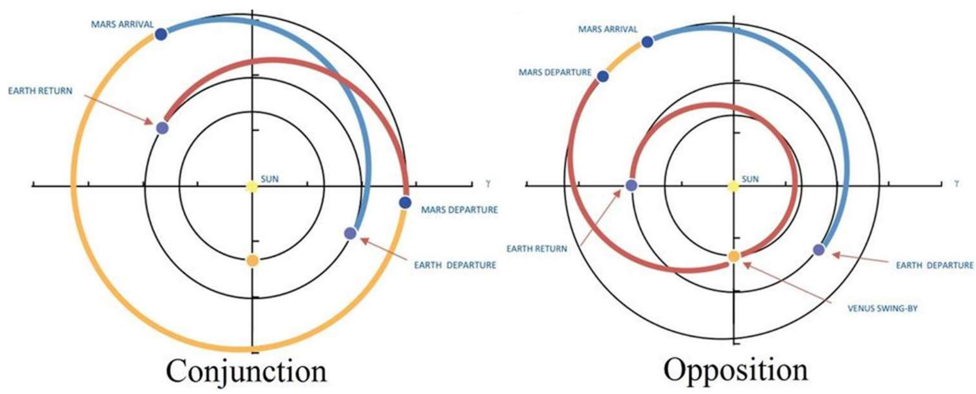

Figure A.6 Conjunction and Opposition type of trajectories
Source: **STI_export_LF99_18141_a1_final-Trajectory_Trades_for_Mars_Missions_062414.pdf (nasa.gov)**