Blue Mars Mission
Group 4 report

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Abstract

The inevitable next step in human evolution is becoming multi planetary. The closest planet mankind can conquer is Mars, our neighbor in the solar system. In the past many unmanned mission targeted the red planet, gathering valuable information. A manned mission could expand our knowledge greatly, and create a path for future errands. This document investigates the habitat and the major areas of research as part of the Blue Mars Mission project, the first ever human mission to Mars. The paper includes recommendations for enroute researches, atmospheric, biological and drilling researches on the surface, and suggestions for the life support systems.

1 Introduction

In the past 50 years, space industry proved to be the most beneficial area for mankind from technological, political and also from economical point of view. To make a next step in space, new technologies have to be developed that will become advantageous in numerous other fields as well. The upcoming challenge for human spaceflight is a manned mission to Mars. The goal of this mission is not just exploring a distant planet, but also investigate the difficulties of a trans-planetary trip and establishing settlement on a barren planet. To accommodate a future habitat, first we need to deepen our knowledge on the red planet, and research the present conditions.

One of the most crucial topic from a human point of view is the composition of the Martian atmosphere. Atmospheric research has been done in the past, but to have a better understanding of Martian environment and the composition of the atmosphere, a more thorough investigation has to take place.

For a future habitat, another critical topic is biological research. Human can create artificial environment for short stays, but to settle, a self-supporting environment has to be established. Plants are irreplaceable parts of such a system. Therefore planting experiments have to be done to examine how they react to the hostile Martian environment, and what has to be provided for them to survive. The cradle of life is water, which is expected to find on Mars in smaller quantities. It is interesting to seek for, not just to supply a future human habitat, but also to understand the history of Mars, and examine if life could develop outside Earth. The best chance to find water is under ground. Drilling on Mars can also explore the composition of Martian ground, and minerals laying in it.

Human aspects also has to be taken to account during the first mission. It includes the long trip to and from Mars and the stay on the surface. To withstand the psychological stress of the long isolation, the astronauts have to stay active by doing en-route researches, and also the habitat has to be as stress-free as possible. The habitat has to satisfy certain requirements in terms of weight, comfort, reliability, power and resource sufficiency and robustness. Since it is going to be the home of the astronauts for months, its design is crucial both from technical and psychological aspects.

The task is to consider all the research topics for our 586 days mission. The main goal is explore the red planet and create a suitable environment for the astronauts during their voyage.

2 En-route Research

The astronauts will stay in their transit habitat for 304 days on their flight to Mars and 160 days on their way back to Earth. During this long time they will have time for doing research beside their normal workload. Research on the interplanetary vehicle is very expensive therefore it has to focus on topics which are important for future long term flights and which are related to a stay on Mars. Studies that can be done on ISS for example, are not taken into consideration. The astronauts will carry experiments about atmosphere, plant growing and geology on Mars and will bring back samples to the transit habitat. On their way back to Earth, they can examine the samples and do research.

2.1 Human Physiology

Except for the Apollo flights, a human has never left the Earth's magnetosphere and has not been exposed to higher solar and galactic radiation than in Lower Earth Orbit. It is important to measure the radiation impact on humans. Therefore a science rack for studies of human physiology will be installed on the transit habitat. This can be designed similar to the European Physiology Module on ISS [1].

2.2 Plant Growing during Flights

For future long term spaceflights, it is important to know how plants can be grown for food supply. Vegetables, like lettuce, and wheat growth in weightlessness can be studied. The Chlorella algae don't need much resources and serve as food supplement [2]. A human being needs 0.5 kg of dry food per day [19], hence for this mission 928 kg of dry food are needed only for the interplanetary transit of this mission. The future goal is to harvest plants on the transit vehicle to cut down mass costs and supply the crew with fresh food. A key factor for mass cut down will be the processing of biological waste (feces, rests of food) to create a closed loop for food supply.

2.3 Equipment for en-route Research

Two science racks for plant growing on the way to Mars and for sample analysis on the way back will be in the transit habitat. They will be designed as multi-purpose racks to save mass. All science racks will be similar to the European Drawer Rack [3]. Figure 1 shows this type of rack. Due to its modular construction, it is flexible for different experiments.

Figure 1: The European Drawer rack [3]

The usage of standardized equipment cuts down development costs. In one of the multi-purpose racks, a glove box will be installed for sample analysis or studies under special atmosphere. Each science rack has a mass of 500 kg and a power consumption of up to 500 W [4]. Hence the total mass of research equipment for the transit habitat is 1500 kg. It has to be considered that his mission is a human mission. The astronauts could do other activities in addition to research. Music connects people and it is important that there is a strong team spirit in the crew. Therefore we propose to have a digital piano in the transit habitat.

3 On-Mars Research

Research on Mars is one of the main goals of our human Mars mission. First the surface habitat is described and after that the research is explained, especially the atmospheric, geologic and planting investigations.

3.1 Mars Habitat

The Mars surface habitat has to be designed for a crew of 4 humans for a stay of 112 days. Due to relatively high ΔV of the trajectory and budgetary constraints, it is only possible to land a maximum of 40 t on Mars. This mass has to include the habitat, its life support system, consumables and the research equipment. Due to these restraints the habitat will be a monolithic habitat. The habitat will be designed similarly to the option presented in [17]. Figure 2 shows this habitat.

Figure 2: Mars surface habitat designed by Lunar Architecture Team 2. [17]

It consists of the descent stage and an inflatable living and working area with a size of 33.5 m^2. The habitat has a total weight of 12.3 t. The biggest advantage of inflatable structures is that they can be compactly packed. NASA developed the "XTC-4" composite wall which consists of different layers for thermal insulation and has a flame and gas barrier included. The material has also a foam layer as protection against impacting small stones. Due to the strong sandstorms, which are possible on Mars, we propose this material to be used for the habitat [18].

Water and oxygen will be produced by an ISRU plant using CO_2 from Mars and H_2 brought from Earth. Water can be produced with the reaction $CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$. A human being needs 3.9 kg of potable water and 23.7 kg of hygiene water [19]. Assuming a water recycling rate of 80 %, the total amount of water is 2473 kg, so that 274.8 kg of hydrogen have to be brought from Earth.

We propose to produce oxygen with the reaction $2CO_2 \rightarrow 2CO + O_2$, because this reaction does not need any additional reactant from Earth. If this production of oxygen is not possible in the future, oxygen can be produced by electrolysis of water. A human being needs 0.92 kg of oxygen per day. In this case additional 64.4 kg of hydrogen would have to be brought from Earth, if the remaining hydrogen of the water electrolysis is recycled.

The power supply is a nuclear reactor on a power cart, which will be brought with the ascent vehicle. After the habitat module and the ascent vehicle have landed on Mars, the power cart drives automatically from the ascent vehicle to the habitat carrying a power cable and pipes for oxygen and water. The cable and pipes are automatically connected to the habitat. The power cart drives than 1 km away from the habitat to reduce the radiation at the habitat's position. The final setup is shown in Figure 3. This setup is chosen, because CH_4 and O_2 for the rocket fuel of the descent vehicle have to be produced. When the crew arrives on Mars, all rocket fuel will be produced and the ISRU plant is switched to life support mode.

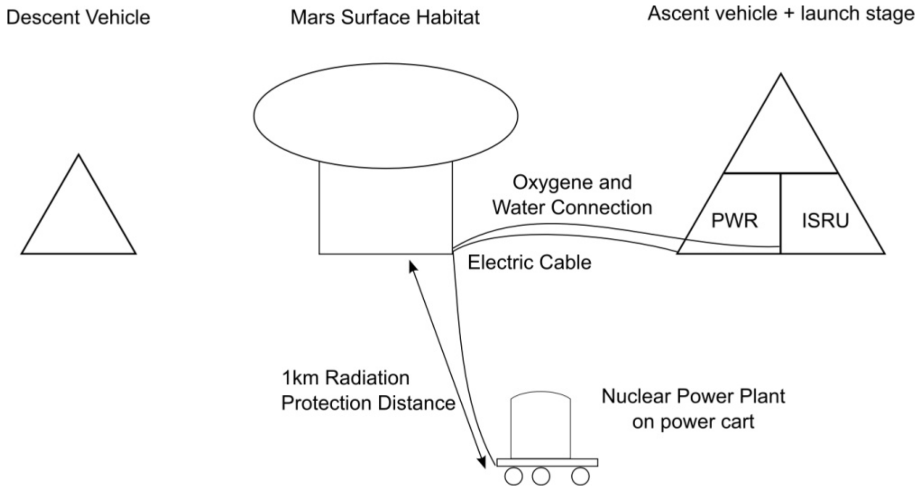

Figure 3: Mars surface habitat designed by Lunar Architecture Team 2. [17]

Redundancy is achieved by a small ISRU plant in the Mars surface habitat and an additional small nuclear reactor. This will add additional 3 t of mass. Due to security reasons oxygen and water for 3 days will be brought from Earth. If even a manual connection of power cable, oxygen and water pipes to the habitat fails, the crew can stay in the habitat for 3 days and prepare the ascent.

Mars habitat, consumables, redundant life support systems and research equipment have a mass of 24.6 t. Details are shown in Table 1. This mass fulfills the mass constraints given by Group 2.

3.2 Atmospheric Research

Additionally to other research programs, Mars' atmosphere is an important topic. This section contains a rough overview about the Martian atmosphere now, different types of research instruments – and furthermore - problems and other topics, which are interesting for a human settlement on Mars.

3.2.1 Atmospheric composition

Previous research programs have already shown the most common components of Martian atmosphere. The bar graph of Figure 4 demonstrates these atmospheric abundances of Mars.

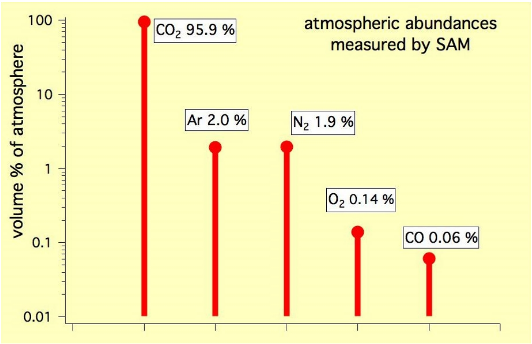

Figure 4: Composition of Mars' Atmosphere [5]

The vertical axis represents the volume % of atmosphere in a logarithmic scale. At the horizontal axis, there are the different abundances in order to their percentage shown. The graph show that the highest Martian atmosphere abundance is carbon dioxide followed by the second biggest components Argon and Nitrogen, but just about 2 % each. The most important element for life of human beings – oxygen – has just a percentage about 0.14 %. With this portion, it is impossible for human beings to breath. To examine the real structure of the Martian atmosphere, it is necessary to collect particles from different altitudes. These particles can be examined later, and its structure can be compared with Martian and Earth soil particles. This research, using collected Martian atmosphere samples, takes place on the surface of Mars in a lab.

3.2.2 Research from surface

The second part of the atmospheric research program is done with spectrometers from the Martian surface, including a mass spectrometer, which investigates the full range of atmospheric gases.This measurement is also capable of collecting samples of soil and particles of the Mars atmosphere. These samples are transfered then to earth for other tests and as samples declaring the proud and glory, that mankind have achieved Mars. These features are seen at the geological research section, where the ingredients of Martian soils and rocks are tested. Furthermore, the research should also focus on the Mars atmosphere as a whole. Different studies state that „[t]he present atmosphere of Mars is 100 times thinner than Earth's [5]". Besides the influences to the human body, it is also important how this is reacting to bigger particles in the Martian 'air'. The experiment shall give a statement about this declaration – either confirm or rebut.

3.2.3 A balloon on Mars

For all atmospheric research, a measurement is needed to collect samples of the air. The idea is to lift up a huge balloon, made of a very hard but elastic material, to the air of Mars. In 2009, there has already been a research about a low-cost balloon mission to Mars and Venus at the Californian Institute of Technology. This program proposed to take a "spherical Mylar or pumpkin balloon made of Mylar or even of polyethylene film [. . .] for the first Mars balloon missions [6]". This film is "typically about 20 μm thick [7]". The negative aspect of a balloon mission is that "a 2 kg payload on Mars would need [balloons] of 10 meters diameter [6]". The following formulas were needed for estimations: The mass of the filling is $m_{\text{filling}} = V\rho = r^3\pi\rho_{\text{H}_2/\text{He}}$ and the weight of the material $m_{\text{material}} = \rho A d = r^2\pi d\rho_{\text{Mylar}}$ (with mass a, radius r, density of hydrogen , helium or Mylar ρ and thickness of Mylar film d). The specific densities are listed in Table 2 and d is 20 µm. According to the example with 2 kg payload for a diameter of 10 m are the masses for the filling for hydrogen $m_{\text{H}_2} = 35.3\,\text{kg}$ and for helium $m_{\text{He}} = 70.3\,\text{kg}$, for the material is $m_{\text{Mylar}} = 8.67\,\text{kg}$.

However, for a few experiments, the payload for the measurements is lighter and so the volume is much smaller. The size is also depending on the material of the balloon. Until the mission to Mars, it is probably possible to have new materials, weight much less than these proposed materials. For the filling of the balloon there were two gases considered. On the one hand hydrogen and on the other hand helium. The favors for hydrogen are the light mass and for the ISRU (In-situ Recoverable Utilization) hydrogen is needed so it is easier to carry more hydrogen in the same tank than carrying a new tank with helium. Besides all additional problems like the pressure, bottle, etc., hydrogen is very diffusible. Helium is also a very light and not as reactive and diffusible as hydrogen, but regarding the weight and transport it is perhaps not as good as hydrogen. Overall, the preferred filling of the balloons will be Hydrogen, but helium is used as a backup for a few balloons.

3.2.4 Measuring equipement

The experiment is done at different places with one balloon for each place and for every second place one additional balloon as a backup. Figure 5 shows the balloon with a measurement box, fixed at the bottom of the balloon. For the first start at each place, the balloon is connected through a line to the surface module and is collecting data and samples. During the way up, the measurement box takes some samples, measures it simultaneous, and sends it back to the station. Every few meters, the instrument takes a sample, to keep it for a research of other ingredients or reactiveness in other environments.

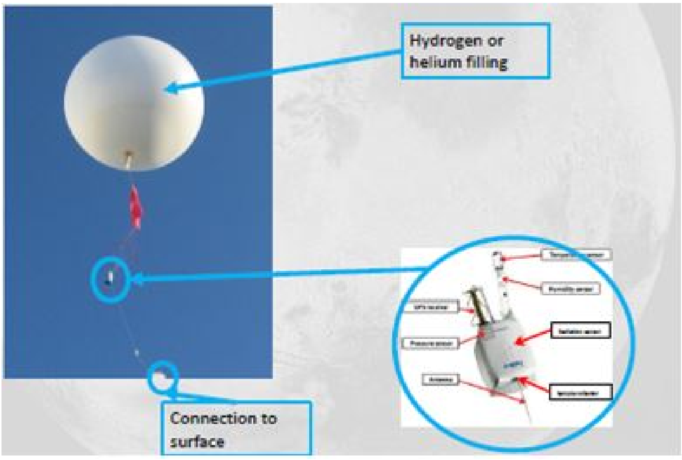

Figure 5: Measuring Balloon

After measuring, it is pulled back by the rope to the platform. Then, the line is removed and the collected samples were brought to the station for a better research on earth. After this, the balloon is lifted up a second time, but now without a line. It is collecting and measuring the samples synchronic without taking samples until it reaches end. The main measurement topics are temperature, particles and radiation, but also other interesting things like winds, dust or how high the balloon can actually lift up.

3.2.5 Environmental problems for the research program

As a resume, all programs can only take place, if the mission and especially the planning of the mission is aware of giant dust storms on Martian surface, seen in Figure 6, titled with 'Mars Dust Devils', and start the program just when thy know that there is not a high risk. For the research of these storms a satellite, which can be brought in a further mission, is obligatory.

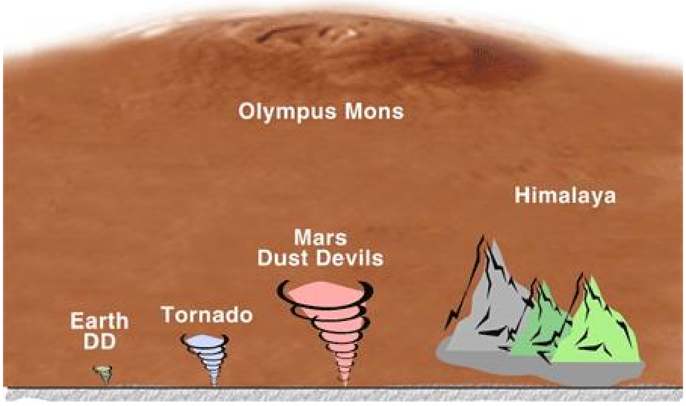

Figure 6: Martian dust storms, [8]

Further questions will be, if there are asteroids effecting Martian atmosphere and if so how and how often or if there are any comparable influences on Mars to establish an Earth-like atmosphere and if not, are there any usable components. There are many other things to search, like Sun influences regarding temperature, especially the heat capacity, radiation or consequences of solar storms. Unfortunately, this would be too much for this short paper.

3.3 Geologic research

One of the main research topics on Mars involves studying its geology. Studying Mars' rocks and soil can give us clues about several matters such as the history of the planet (and even of the Solar System), the presence of water in the past, the composition and abundance of different minerals and metals that can be useful for humanity, and even the possibility that Mars once held life.

3.3.1 Location analysis

Choosing the location where the crew and the habitat will land is crucial and will largely impact the outcomes of the mission. There are several considerations to be taken into account when choosing the landing spot for our Mars mission. These include the presence of a crater, the elevation, the geomorphology of the terrain, the roughness and the presence of certain materials that point to the existence of water in the past.

Following the studies made by NASA when choosing the location for the Mars Science Laboratory (also known as Curiosity), several candidates were identified [9]. Of all these, there is one in particular that stands out for the kind of mission that we are undertaking. It is the Eberswalde crater site, located south of the Martian equator, and it is shown in the figure below.

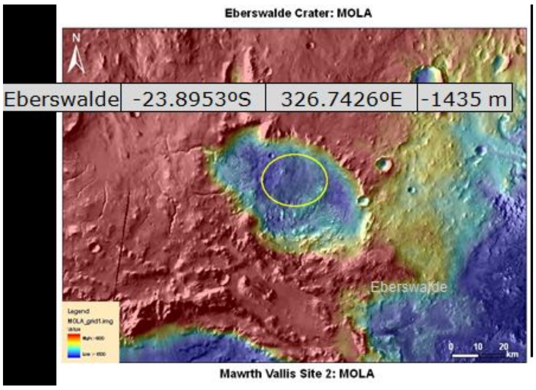

Figure 7: Eberswalde crater location, credit: JPL/NASA

This particular location has several interesting features that make it optimal for the establishment of the Martian base. First of all, the crater is close to the equator, which is always better when trying to land on a planet, since there's more atmosphere that can be used for aerobraking. The low elevation of the site also provide more atmosphere to work with, higher pressures, and relatively higher temperatures, all useful for planting research.

Another interesting feature of this particular site is that there is satellite evidence of the presence of a fluvial-deltaic system where an ancient river entered a standing body of water [9], which can give a lot of insight into the processes of sedimentation as well as other climatic and hydrologic conditions in the history of Mars.

The presence of an ancient lake, and therefore of several clays and other deposits brings the opportunity to look for biogenic materials [10], i.e. deposits where organic materials have been preserved. This can provide some insight into whether there was any life on Mars in the past. Studying the lake bed would also let us know more about how all these minerals were deposited at the bottom, layer after layer.

Another advantage is that this particular crater is one of the smoothest and flattest regions that have all of the abovementioned qualities. This makes it easier to set up the whole mission on the site, giving facilities for planting, greenhouse deployment, rover driving, and sample collecting.

For all the reasons mentioned above, the particular location shown in Figure 7 at Eberswalde crater has been deemed the most suitable for our Mars mission.

3.3.2 Sampling operations

A very important part of geology research is collecting all kinds of samples that we can later on analyze. A return mission to Mars gives a huge opportunity of acquiring samples of Martian rocks and soil and bring them back to Earth in a first-of-its-kind expedition.

In order to collect and analyze those samples, adequate equipment is needed. To gain some insight on the geological processes described in the last section, several instruments can be used for different purposes. First of all, some machine with drilling capabilities is needed to collect drill cores of the soil. We can propose two different solutions; first, a self-penetrating probe, similar to the one planned to be used in the InSight mission [11], which is shown in the figure below.

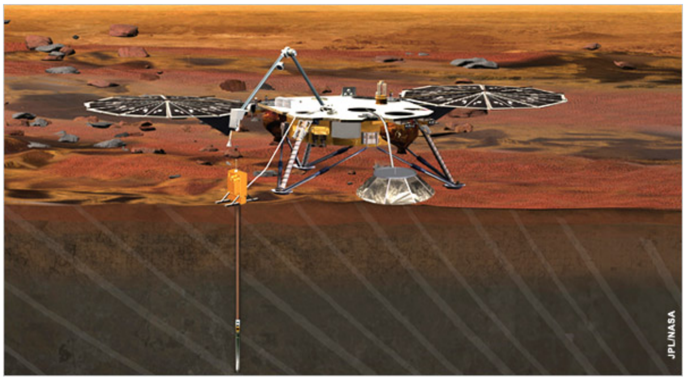

Figure 8: InSight probe model, credit: JPL/NASA

This would allow us to probe up to a few dozens of meters below the surface of Mars, collecting samples from the deep soil and rock, and also taking advantage of the hole by placing temperature sensors along the drill that can tell us about the heat dissipation coming from Mars' core.

On the other hand, a manual, more portable drill (e.g. one using a battery) could be carried by the astronauts or placed in the rover so that they can sample zones of more difficult access and operate it with relative easiness. The weight of these drills combined could be up to 1000 kg.

A different kind of instrument could be a Seismic measurement system that explores the Martian tectonic activity (if any) and measures any kind of internal Martian activity that can tell us something more about the planet's geological history and also internal structure. A simple seismometer can be used, for example, and it would not suppose a large investment in mass or power.

Finally, the astronauts should also collect as many samples of soil as they can from different parts of the ancient lake bed, so that (as mentioned before) they can look for organic signals that point to the presence of life in the old Mars.

3.4 Planting

To settle on other planets and sustain life without supplies from Earth, we will have to plant to satisfy human oxygen and food demands. This task is slightly more complicated than it seems. In case of Mars we have to overcome the following problems:

3.4.1 Pressure

The average of Martian atmospheric pressure is 600 Pa, about 0.6 % of Earth's mean sea level pressure. For plants, it is impossible to survive these conditions, since they have no evolutionary preadaptation to hypobaria. To overcome this problem, we have to build pressurized greenhouses. The required pressure can be built up partly from the Martian atmosphere, because it is built up mostly from CO_2, the only gas plants require, but we have to be aware, that partial pressure of $\mathrm{CO_2}$ on Mars is around 7.1 mbar (on Earth it is 0.31 mbar), and even for plants, $\mathrm{CO_2}$ above 1.5 mbar is toxic [12].

As a result, most of the pressure has to be built up by "normal" air, which is costly to carry to Mars. Reduced pressurized greenhouses might seem advantageous but in our case it is necessary and reasonable to build up near-Earth pressure. Plants interprets low pressure as if they are drying out. To survive, they require much more water, which is one of the most precious resource on a distant planet. Water also weighs more than air, therefore it is also more economical to provide the required pressure for the plants instead of increasing their water supplies. From a biological point of view low pressure has more disadvantages: even if the increased water need is satisfied, they still interpret accelerated water movement as drought stress, and they waste their resources [13].

3.4.2 Soil

Another essential source for plants is the soil that supplies minerals for them. Martian soil is slightly alkaline (pH 8.3) and contains elements such as chlorine, magnesium, potassium and sodium, which are necessary for growth of plants. There are 13 mineral nutrients recognized as necessary supplies for plants from soil, divided into two categories; macro- and micronutrients.

The primer macronutrients are nitrogen, phosphorus and potassium, consumed in large amount by plants. Secondary nutrients, calcium, magnesium and sulfur are usually supplied by slow decomposition of soil organic matter. In our case we need to add some initial calcium and sulfur to start the growing cycle, but hereinafter no additional supplies are required.

Micronutrients are like secondary macronutrients in terms of supply, since plants need them in very small quantities. These minerals are boron, copper, iron, chloride, manganese, molybdenum and zinc [14].

The ideal pH for planting is around pH 6.5 (slightly acidic), which is lower than the natural value of pH 8.3 of Mars. Ammonium sulfate is one of the most commonly used acidifiers, which is also suitable for our mission.

To create suitable soil for planting, all the above mentioned ingredients have to be mixed in the appropriate volumes respectively. By adding water to the soil, plants can absorb the necessary nutrients, and grow.

3.4.3 Water

As it has been mentioned, water is crucial for plants to grow and survive. Water consumption of plants depends on temperature and pressure in the greenhouse. Since we assume that there is no water supply on Mars, and we need to carry all the water from Earth, it is our interest to keep plants' water consumption as low as possible. To create the appropriate environment for the minimum water consumption, we need to consider the variety of plants we want to grow. This has to be examined from several aspects, and will be done later in this report.

3.4.4 Sunlight

Sunlight is indispensable for plants to grow. Although it can be substituted by UV lights, it is more efficient to use the sun. Martian days are roughly as long as they are on Earth, but the solar intensity is approximately 43 % lower. It also varies widely, since the difference of Martian perihelion and aphelion are larger than Earth's. Table 3 shows a comparison of Earth's and Martian solar intensity.

The table shows that the average solar radiation is about half on Mars compared to Earth. On the surface however the solar energy per unit area is higher on Mars than on Earth due to the much thinner atmosphere. It also results in an extreme amount of ultra-violet radiation, which has to be filtered by the walls of the greenhouses.

3.4.5 Temperature

Since Mars has a very thin atmosphere compared to Earth, the temperature varies on a much greater scale. It is also further away from the Sun, therefore the mean temperature is lower, around $-55\,^\circ\mathrm{C}$ [15]. Although greenhouses have some thermal reflectivity, it is not sufficient enough to obtain a reasonable temperature continuously. To overcome this issue, we will need to install heaters inside the greenhouses, or attach them to the habitat's air conditioning system.

3.4.6 Installation

On our mission we plan to set up two $50\,\mathrm{m}^2$ greenhouses: one with near-Earth conditions; mean temperature around $25\,^\circ\mathrm{C}$, pressure around 100 kPa, UV protection and all the necessary minerals mixed in the soil that is required for plants. The goal of this greenhouse is to produce food, mainly vegetables, and oxygen for the astronauts. The habitat will have independent food and oxygen resources in case the experiment does not succeed. In the second greenhouse we plant the toughest plants from Earth, which are capable of surviving extreme circumstances.

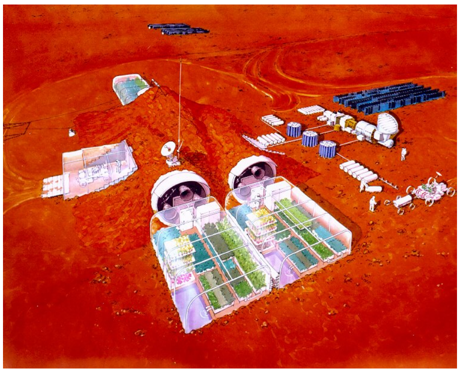

Figure 9: Possible layout of the greenhouses, [13]

In this greenhouse we let the temperature vary on larger scale, we provide limited UV protection, and feed minimal minerals to the soil. A huge variety of plants can be considered [16]. The goal is to observe and experiment how they react and adopt to these conditions, and find the most resistant plant which can be used to produce oxygen with the least support. Genetically engineered plants has to be also considered, modified to withstand high UV-B radiation, drought and high changes in temperature.

3.4.7 Required equipment

To build a greenhouse on Mars, we need to consider the following equipment. First of all we have to take the structure of the greenhouse and a sealed covering material. It has to be strong enough to withstand the enormous pressure difference but also light to minimize transport costs. A suitable material for the structure is carbon-fiber, and for the cover a strengthened plastic foil. They are both strong and flexible enough to withstand the physical stresses. The plastic foil can also protect from UV radiation.

To present the required pressure in the greenhouses, a generator has to be set up. It can be attached to the habitats Life Support System, and also add some of the atmospheric air. In order to access the greenhouses, airlocks has to be installed.

For the mass budget, all the required supplies has to be considered for plants, such as water, minerals, air, and also the gardening tools. The mass budget can be seen at Table 4.

3.5 Research summary

During the mission on Mars the aim is to examine the planet from core to the top of the atmosphere and everything in-between. Due to the weight and space limitations of the mission, the equipment applied has to be carefully designed and selected, to be functional in the hostile environment of Mars. These tools themselves have also limitations, but our goal was to examine the red planet on a scale as wide as possible. The researches aimed to widen our knowledge on Mars and determine the basic supplies required for future missions or colonies. The goal of the drilling and atmospheric research is to map the available sources, and to discover Mars' history. The biological research is aimed to examine the minimal requirements for a self-sustaining environment for a humans, which produces food and oxygen, and to inspect different plant's acclimation capacity. All these researches will facilitate future missions and move mankind one step closer to become interplanetary.

4 Conclusion

The research on Mars is one of the main goals of the entire mission. Besides putting a man on another planet of the solar system, it is also the first time mankind has the possibility to have a closer look on Martian environment, and do researches which couldn't be done without human assistance. In order to establish a human settlement, this is the first major step. In this paper we aimed to examine all the areas of research, with boundary conditions from other groups of Blue Mars Mission.

Before the 60s nobody could imagine that a man could be on the Moon and now we are planning a mission to Mars. It will be expensive and every participant has to go to his extremes, but in a long run, as history proved in many other cases, it is going to pay off. So that we can say after all, 'it is just a small step to Moon, but a great leap to Mars'.

A Tables

Table 1: Mass summary for surface habitat with a total mass of 24 600 kg.

Item	**Mass** (kg)	**Comments**
Mars Habitat	12,280	Monolithic habitat
Life support	4,591	Including:
EVA suits	750	One suit per crew member, one backup
Hydrogen	275	Hydrogen for water production
Food	224	Dry food
ISRU/Power	3000	Small backup ISRU plant and nuclear power plant
Water/Oxygen	342	Water and oxygen for 3 days
Science	7750	Including:
Planting	4500	Pressurized greenhouses, water and power
Drilling	1000	Drilling equipment
Atmosphere	1500	-
Rover	750	Unpressurized rover for exploration

Table 2: Material and gas densities for atmospheric balloon

Material/Gas	**Density**
H_2	$0.0899\,\mathrm{kg\,m^{-3}}$
He	$0.179\,\mathrm{kg\,m^{-3}}$
Mylar	$1.38\,\mathrm{g\,cm^{-3}}$

Table 3: Sunlight parameters of Earth and Mars

Planet	**Distance** [AU]		**Solar Radiation** $[\mathrm{W\,m^{-2}}]$	
	Perihelion	Apohelion	Maximum	Minimum
Earth	0.9833	1.017	1,412	1,321
Mars	1.382	1.666	715	492

Table 4: Mass summary for planting research with a total mass of 4.5 t.

Equipment	**Mass** (t)
Greenhouse structure and cover foils	1.75
Minerals	1
Air	0.2
Hydrogen for water (ISRU)	0.2
Pressurizer system	1
Airlocks	0.3
Gardening tools	0.05
Overall	4.5

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