HEPHAESTUS : Mission to Mount Olympus Mons Mission Design - Blue Group

Louise Terrien, Kim Lamboley, Jomuel Danilo Costales, Olle Rendlert & Mats Svalstedt

***Abstract*—This report studies the requirements and proposes a solution for the design of the Hephaestus Mission during which at least one astronaut must climb by foot the last kilometer of the highest Mount in the solar system : Mount Olympus Mons, on Mars. Some organizational aspects of how the team worked to come up with this solution will be given before technical solutions are presented. The chosen direct-transfer trajectory will be presented, setting a launch window of 1 month starting in September 2040, a mission time of 985 days and a total back and forth transfer ΔV of around 11.6 km/s requirement to accomplish the mission. Communications during travel using the Deep Space Network will be discussed before going through the whole mission timeline and logistics. The different values of mass required for propellant, life support systems, rovers or spacecraft structure are taken from the other groups' reports. An off-nominal scenario of a trajectory that crosses the path of a micro-meteoroid is considered and solutions discussed.**

***Sammanfattning*—Den här rapporten undersöker vilka krav som finns och föreslår en lösning för designen av uppdraget Hephaestus, där minst en astronaut måste bestiga den sista kilometern av det högsta berget i solsystemet, Olympus Mons på Mars, till fots. Först presenteras några organisationsaspekter för hur gruppen arbetade för att komma fram till den här lösningen, varpå den tekniska lösningen presenteras. Banan för farkostens direktöverföring kommer presenteras, vilket ger ett uppskjutninsfönster på en månad från och med september 2040. Uppdraget förväntas ta 985 dagar och kräver en total ΔV på ungefär 11.6 km/s. Möjligheten att använda Deep Space Network under resan kommer diskuteras, för att sedan presentera uppdragets tänkta tidslinje och logistik. Värdena för massan av bränsle, livsupphållande system och alla olika farkoster finns att se i de övriga gruppernas rapporter. Ett abenglisnormalt fall där en mikrometeorit korsar farkostens bana presenteras och lösningar till detta föreslås.**

***Index Terms*—Human Spaceflight, Mars, Mount Olympus Mons, Mission design, Timeline, Logistics**

Supervisors: *Christer Fuglesang, Anna Hidalgo Larsson, Erik Clacey*

SYMBOLS

a	Semi-major axis
DSN	Deep Space Network
ISS	International Space Station
LEO	Low earth Orbit
T	Orbital period
ΔV	Velocity increment
μ	Gravitational constant

I. INTRODUCTION

HUMANITY has always been drawn by a mysterious curiosity to explore the unseen and uncover the unknown. Today we are experiencing a rapid development in space technology driven by both private actors and governmental institutions, and the edges of our solar system feels closer now than ever before.

This report will explore the possibilities of a manned mission to Mars, with the goal of climbing the tallest mountain in the solar system, Olympus Mons. The assumption is that several robotic and a few human missions have already been conducted to Mars, and three automated facilities are present on the surface at different locations that produce water, oxygen and methane. No flying vehicles are allowed to land over an altitude of 10 km below the peak and the last 1000 meters of the climb must be done without vehicles.

This Mission design study includes an explanation of the internal and external team coordination, the trajectory choice strategy as well as a analysis of the mission timeline and logistics, consideration about communication during the interplanetary travel as well as an off-nominal case study.

II. TEAM COORDINATION

A. Internal team coordination

Mission design team has met on a regular basis to discuss the project together and split the work between the team members. Jomuel Danilo Costales and Kim Lamboley have been mostly focused on the trajectory calculation and choices. Kim Lamboley and Louise Terrien worked on the mission timeline and logistics as well as the crew composition. Mats Svalstedt studied the communication solutions. The off nominal case has been chosen by the all team and mostly studied by Mats Svalstedt and Olle Rendlert. This report has been written by the five members of the group.

B. Coordination with other teams

In order to thoroughly investigate the goal of climbing Olympus Mons, the project was divided into five groups : Mission Design, Space Vehicles, Mars Operations, General Management and Human Aspects. Coordination with the other groups was a huge part of the work. For example, the space vehicles' group needed the final payload mass for their calculations, which had to be discussed with human aspects to determine the weight of the life support systems and the amount of food, water and oxygen. This amount of consumables depended on the mission duration that mission design group determined. Furthermore, Mars operations had to give their input to the weight of the equipment and vehicles needed to complete the mission on the surface. This weight then needed to be assessed by space vehicles again to determine if the final payload mass was reasonable or not. This kind of back and forth communications between the groups was a key element in the overall mission design.

III. Trajectory

One of the main goals of the Mission Design team is to determine the suitable orbits to follow in order to take the crew to Mars and bring it back to Earth. Two main strategies were considered and analyzed: a direct transfer and a trajectory involving a Venus flyby.

A. Assumptions and Approximations

- Planetary ephemeris provided by JPL HORIZONS system [1]
- Sphere of influence and patched conics approximations
- Impulsive maneuvers

B. Methods

1) Direct Transfer: The direct transfer approach consists in finding the elliptical orbit linking Earth and Mars. Thanks to the patched conics approximation, the sphere of influence of both planets can be assumed to be infinitely small compared to their distances with respect to the Sun. Therefore, the trajectory connecting them can be determined by solving the Lambert's problem [2].

Two ΔVs are computed for each strategy: one performed to inject the spacecraft in the interplanetary trajectory from a circular Earth orbit with 200 km altitude; the other to slow it down in the same circular orbit around Mars.

2) Venus Flyby: To go from Earth to Mars, direct trajectories are not the only avaiable otpions. One of these options is a Venus flyby. The principle is simple : instead of going directly from Earth to Mars, a spaceship can fly from Earth to Venus and use its gravity to accelerate enough to then go to Mars. As Venus's orbit radius around earth is smaller than Earth's, it is not clear if these flyby trajectories will have any advantage compared to direct trajectories for Earth-Mars transfers.

In a 2009 study [3], researchers found that in the timeframe 2020-2040, the position of Venus allows multiple Venus flybys from Earth to Mars. These trajectories create additional launch windows during the traditional 26 months gap between direct trajectory launch window. Unfortunately, the Venus flyby trajectories usually require slightly more ΔV and have an equivalent or longer time of flight but as Venus is closer to the sun, radiation levels received by the astronauts, even for the same time of flight, would be higher than the one received in direct transfers.

Venus flybys are really interesting when wanting to reduce the amount of time on Mars to a few weeks. But, as the human body is weakened by flights in weightlessness, a few weeks only to get back in shape and prepare the Olympus Mons climbing will not be enough for the crew. Some details about the time to recover bone and muscle mass can be found in the Human Aspect Report. Artificial gravity could be used to mitigate this but this technology is assumed to not be ready by the time this mission will happen.

For all these reasons, Venus will not be used neither to go to Mars nor to come back from it.

C. Results

The direct approach is applied to find the all the possible trajectories in a time research window of five years: starting 1.1.2038 up to 31.12.2042. As a result, more than 700,000 different orbits are determined per each trip. In order to have a better visualization of the types of trajectories obtained, the so called ”Porkchop diagrams” are plotted in Fig. 1 and 2.

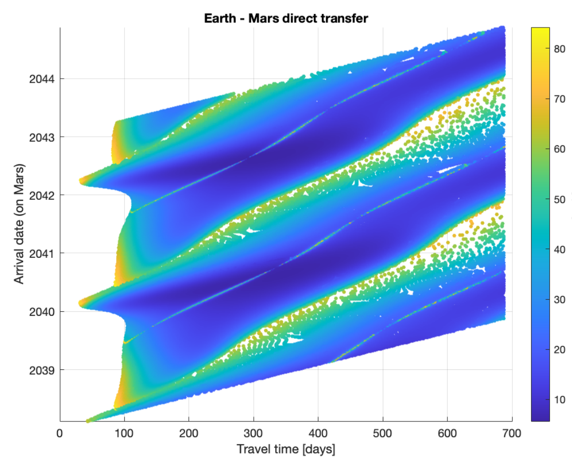

Figure 1. Earth-Mars direct transfer ΔV requirement as a function of arrival date and travel days

According to what the theory is suggesting, there is a pattern repeating almost every 2 years.

A primary filter of $\Delta V_{max} = 8.5$ km/s is applied and is shown in Fig. 3 and 4.

From Fig. 3 and 4, the presence of two possible time windows for each trip is clearer. For the outbound journey, the first time window has its first arrival on Mars in March 2040 whereas the first inbound trip time window closes in October 2039. Therefore, for the Mars to Earth transfer the second time slot, starting in mid-2041, has to be considered.

The two selected time windows can be plotted in the same diagram so that all possible combinations of round trips are displayed. These time windows have been plotted in Fig. 5

Among them there are three choices worthy of attention:

- The trip requiring the least ΔV

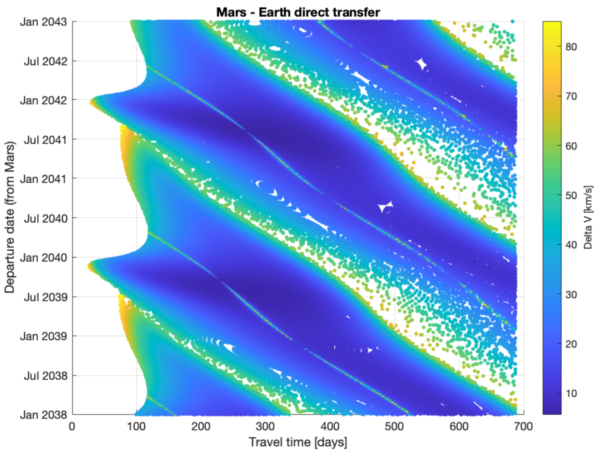

Figure 2. Mars-Earth direct transfer ΔV requirement as a function of arrival date and travel days

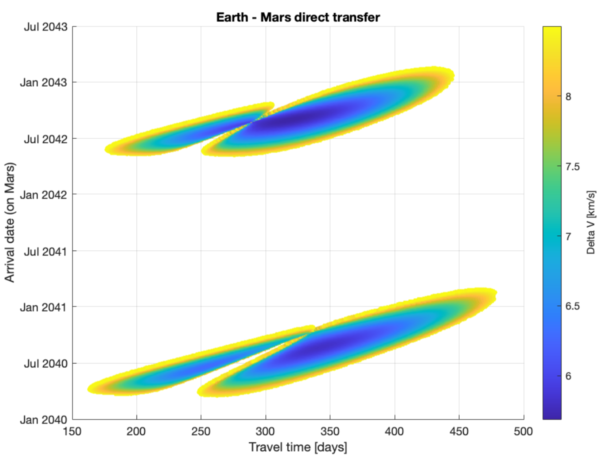

Figure 3. Earth-Mars direct transfer ΔV requirement as a function of departure date and travel days (max $\Delta V = 8.5\ km/s$)

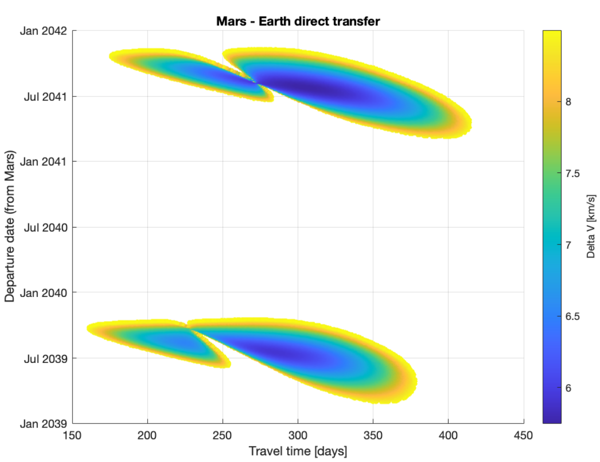

Figure 4. Mars-Earth direct transfer ΔV requirement as a function of departure date and travel days (max $\Delta V = 8.5\ km/s$)

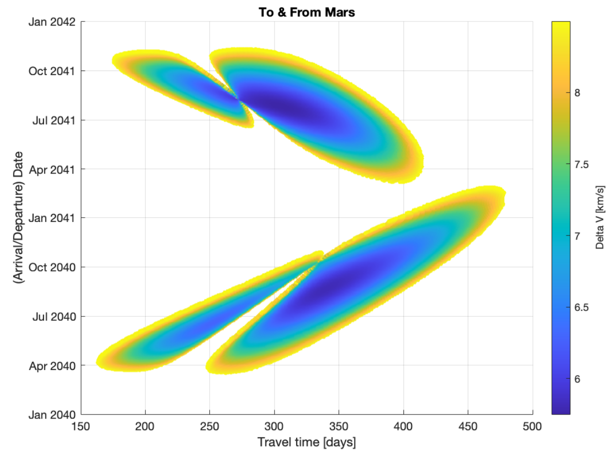

Figure 5. Combined direct transfer ΔV requirement as a function of arrival/departure date (from Mars) and travel days (max $\Delta V = 8.5\ km/s$)

- The trip whose interplanetary travel is the shortest
- The trip whose stay on Mars is the shortest

The latter two are in a way connected: given the fact that the two time windows are already chosen, a longer trajectory would result in a shorter stay on Mars and vice-versa.

Regarding the former option, a more detailed analysis has to be performed. An increase of ΔV would bring to more launch opportunities with a decrease of the travel time (compared to the least ΔV strategy) and mission duration. Therefore the consumables mass (food, water, clothes, oxygen) required is reduced. On the other hand, a higher ΔV would result in more propellant mass needed.

In coordination with the Space Vehicle Group, a rough calculation and estimation is done to further comprehend the entirety of the compromise to be agreed upon. With respect to the most efficient Earth - Mars trajectory in terms of ΔV, an increase of 0.5 km/s can result in a reduction of travel time of 100 days. Thus, in turn, a consumable mass of up to 10 tons is saved. Conversely, the fuel and oxidizer mass is increased dramatically: more than 100 tons have to be added to cover the extra ΔV requirement. The main explanation for this disproportion lies in the fact that the spacecraft dry mass without the consumable mass (e.g. structural mass, rovers, life support systems) already represents a significant percentage of the total mass.

For this reason the combination of trajectories requiring the least ΔV is chosen.

D. Chosen trajectories

In table I are listed the data of the chosen orbits. The first and second burns are respectively the engine firings required to enter and exit the interplanetary trajectory. For each of them the ΔV cost is reported. The values are increased by a $1.1x$ factor in order to take into account a safety margin and mid course correction maneuvers.

In coordination with the Space Vehicle Group it has been decided that the vehicle will perform a direct reentry in the Earth's atmosphere on the inbound journey. This would allow a further saving in terms of propellant mass since the second burn is no longer required.

	To Mars		To Earth	
First burn	2039.9.19	4.1658 km/s	2041.7.30	2.3692 km/s
Second burn	2040.8.25	2.2217 km/s	2042.5.31	3.9547 km/s
Total ΔV	6.3875 km/s		6.3239 km/s	
Travel time	341 days		305 days	

Table I
CHOSEN TRAJECTORY PARAMETERS SUMMARY

A graphical representation of the onward and return trajectories from Earth to Mars and back is given in Fig. 6 and 7.

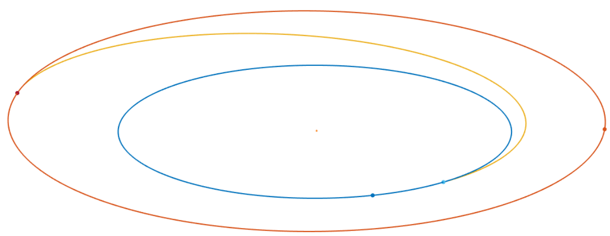

Figure 6. Trajectory from Earth (blue orbit) to Mars (red orbit)

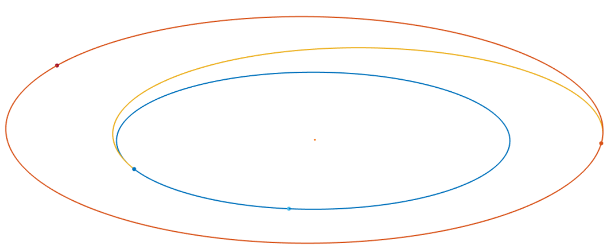

Figure 7. Return Trajectory from Mars (red orbit) to Earth (blue orbit)

E. Time window

When dealing with space missions it is better to have some flexibility regarding the launching dates. Especially with complex missions like this one, delays through the various required steps prior departure are highly probable. In particular, for this mission the major instant time constraint is given by Earth and Mars positions so that the chosen interplanetary trajectory can be performed correctly. Therefore one way to mitigate the delay effects on the mission success is to launch the vehicles in LEO in advance with a discrete time margin. In this time period refueling and ultimate checks are conducted before the escape burn.

A time window is found in case the maneuver, for any reason, cannot be performed in the chosen departure date. From the calculated trajectories a filter on the maximum ΔV allowed is applied. That value corresponds to the ΔV of the chosen trajectory raised by 1% (0.0639 km/s) in order to allow more possible dates. The margin is kept low because of the compromise on the propellant mass needed.

With these constraints, the time window is of 17 days:

- Opening date: 19.09.2039
- Closing date: 06.10.2039

F. Free return trajectory

As for the Apollo missions, a study of a free return trajectory has been performed. This type of orbit allows a safe return to Earth in case a propulsive system malfunction prevents the vehicle to perform the trajectory correction maneuvers or the firing needed to enter Mars orbit.

As a first approximation the gravity effect of the red planet is neglected during the fly by. The resulting problem is to find the trajectories that are synchronized with the motion of the Earth; that is to say those which have an orbital period equal to an integer multiple of an Earth year. Knowing the orbital period equation of a trajectory around the sun, the required semi-major axis for a free return trajectory can be calculated:

$$a_{FRT} = \left[\mu_{sun}\left(\frac{n \cdot T}{2\pi}\right)^2\right]^{\frac{1}{3}}, \text{ n=}1, 2, 3, ... \quad (1)$$

The ΔV requirements for free return trajectories are given in Fig. 8 for a return after 1 Earth year and in Fig. 9 for a return after 2 Earth years.

It can be seen from the graphs above that this type of maneuver requires a much higher ΔV than the chosen one (at least 10 km/s). As a result the propellant needed would skyrocket. After an internal group analysis and a whole team discussion it has been concluded that the initial strategy should be followed. The team should therefore focus into the implementation of several redundancy systems in order to prevent the mission from needing a free-return trajectory.

IV. CREW COMPOSITION

The crew size and composition is a really important part of such an operation. Indeed, this kind of mission is very long, the possibility to get material help almost impossible and the communication is not instantaneous. Therefore, the crew should be able to work together for a long time as a

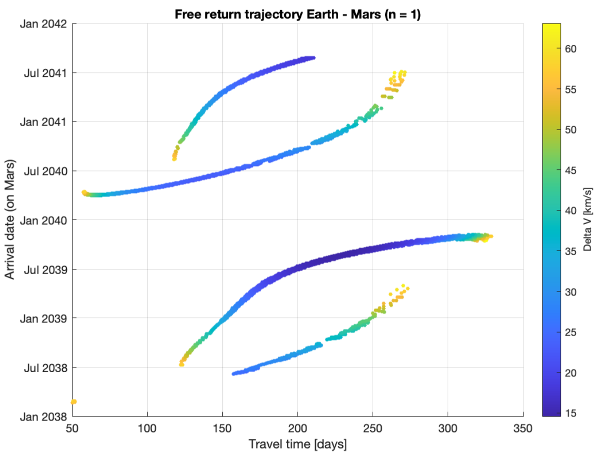

Figure 8. Free return trajectory ΔV requirement as a function of Mars arrival date and travel time for a return after 1 Earth year

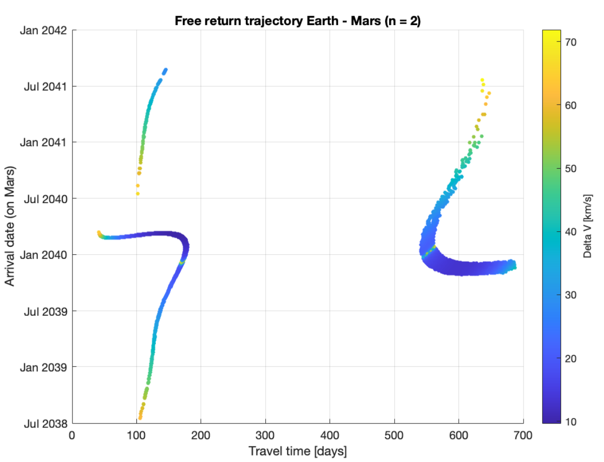

Figure 9. Free return trajectory ΔV requirement as a function of Mars arrival date and travel time after 2 Earth years

team and have all the skills that could be needed to make the mission successful. A crew that would be too small would reduce the possibility of having various skills and could pose some social problem as it can cause psychological problem to only see a very small amount of people for a long time [4], but each member of the crew will increase greatly the life support system size as well as the food amount needed for the mission resulting in an increase of the price. Considering the long mission time and various stages needing personnel on Mars a crew size of six astronauts was selected, three female and three male. In order to increase both the budget and public relations of the mission one of the crew members will be a paying guest, while the other five are professional astronauts. However, considering the scope and difficulty of the mission the paying guest will have to have compatible skills and undergo rigorous training. The crew members will be chosen for their skills as well as their motivation, mental and physical health as well as their capacity to work as part of a group and make good decisions under pressure. The crew selection team will make sure to constitute an international crew with three women and three men. The technical skills considered most important for the astronauts are Mechanical engineering, Electrical engineering, Pilot and Medical Doctor, specialized in surgery with some skills in psychology. The title, main skill and secondary skill of each member of the crew is presented in Table II. All of them, including the paying guest, will have a basic medical training as well as an astronaut training (basic training, specific mission training as well as on-board training). The crew will have assigned roles during all of the mission.

Title	Main skill	Secondary skill
Guest		
Commander	Mechanical Engineer	
Spaceship Pilot	Mechanical Engineer	Pilot license
Mission Specialist 1	Electrical Engineer	
Mission Specialist 2	Medical Expert	Surgeon / psychologist
Mission Specialist 3	Astrobiologist	

Table II
CREW COMPOSITION

V. COMMUNICATION

Due to the large distance between Mars and Earth there is a significant time delay in communications. The delay is not caused by insufficient technology, instead being a result of the fundamentals of physics. Essentially, signals cannot travel faster than the speed of light in vacuum. It can therefore be inferred that the technology used today will still be relevant at the time of the mission. It takes a minimum of 8 and a maximum of 48 minutes to send a message and receive an instant reply from Mars (and vice-versa) [8].

The NASA Deep Space Network (DSN) consists of three large spacecraft communication facilities that are spread across the world, approximately 120 degrees apart [6]. Through the use of the widespread facilities, NASA is able to maintain communications almost constantly with spacecrafts during interplanetary missions. Since there are no communications facilities on Mars, events such as solar conjunctions may cause disturbances in communications with spacecrafts during the missions as the linear signals get intercepted by the sun. Solar conjunction occurs for two weeks and happens every other year. A solution to this problem is to launch a multi-functional satellite in an orbit around the sun. It can be used to intercept the signals and in this way, maintain the communication between Mars and Earth during solar conjunction. Using a multi-functional satellite that also gathers data from the sun is motivated by potential funding.
The Perseverance rover that landed on Mars in February 2021 uses three antennas in order to achieve full telemetry [5]. All three use current satellites in orbit around Mars. The Ultra High frequency antenna is the primary antenna and manages to send the largest amount of data, which is done at a maximum rate of two megabits per second. Furthermore, the X-band maintain redundancy for the system by transmitting

data at a speed of $800/3000$ bits per second to the DSN. The primary use of the antennas will be for communication and information exchange, rather than transfer of heavy data. These antennas are therefore considered sufficient enough in achieving the necessary demands put on the system and thus integrated into the spacecraft.

Local communications as well as ground navigation once on Mars will be achieved using the Monarch project and are more thoroughly discussed in the Mars Operation report.

VI. Time Line and logistics

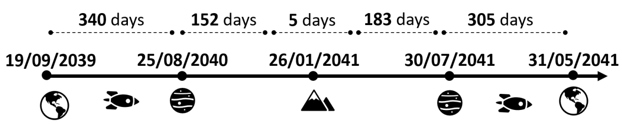

Figure 10. Mission Timeline

To reach the goal, the mission needs to have a clear timeline and logistics concerns need to be planned well in advanced. This section will set the constraints and course of actions for the five parts of the 985 days mission as presented in the timeline in Fig 10.

A. Earth take-off and on orbit preparation of the trip

If the first day of the expedition is the 19^{th} of September 2039; understand departure from Earth orbit for the trip to Mars; the first launch of the mission will take place at least 7 days before. The mission will be realised with 2 ships as described in the Space Vehicles report, the first one will be the unmanned crew spaceship and the second one a cargo spaceship. Both will be propelled with $1,200$ tons of liquid propellant, a mix of liquid methane and liquid oxygen. They will have a payload of 30 tons each. They will take-off from Cape Canaveral, Florida, United States, with an inclination of $28°$. In addition, both ships will be able to sustain a crew as they will both have the full complement of Life Support Systems. As the trip to a Low Earth Orbit from the surface is already really expensive in terms of propellant amount, the vehicles will stay until departure in a 200 km of altitude circular parking orbit around Earth. They will be refueled by seven Starship tanker versions also launched from Cape Canaveral. The crew will take-off on a refuelling vehicle on the day before launch, reaching the crew mission vehicle. This will reduce their time in space and thus the amount of consumables that will be taken for the mission. Additionally, this will also reduce the risk for the crew if something goes wring during one refuelling.

This section exposes a time-line based on the 19^{th} of September 2039 but it may be subject to small changes in case the launching date has to be delayed. As stated in Section III-E, the launch window is opening on the 19^{th} of September which is the cheapest day in terms of travel cost but it will be opened until the 6^{th} of October without posing any problem in terms of payload mass and fuel needed to perform the trip.

B. Outward journey

On the 19^{th} of September 2039, the six crew members will be seated in the crew vehicle. The ships will perform a 3.8 km/s escape burn to change attitude and enter in a direct trajectory to Mars as described in Section III. During the 341 days of travel from Earth to Mars, the vital functions of the astronauts will be ensured by the life support systems which are detailed in the Human aspects report. Each member of the crew will consume about 1.5 kg of dehydrated food per day as well as 0.8 kg of oxygen and 5 kg of water for drinking, food preparation and hygiene. About 90% of the water will be recycled and the required oxygen will be produced on-board. The rest of the water will be carried in water tanks. The metabolic waste as well as the air circulation and management will be ensured by the Life Support Systems. The communication devices used during the trip are described in Section V. After 341 days of travel, the ships will perform a 3 km/s burn to enter a 200 km of altitude, circular low Mars Orbit before they land on Mars surface. The vehicles will land on Gusev Crater which is situated 14.5°S ; 175.4°E on Mars surface. The landing process will be described in the Space Vehicles report.

C. Preparation of the expedition

Around August 25^{th} 2040, after almost a year spent in space in a zero gravity environment, despite the daily sport training's, the bones and muscle mass of the astronaut will have decreased a lot. In order to maintain a good physical shape, the crew will stay for five months at the base. Most of their time dedicated to training. It is also a good way to give their body time to get adapted to the martian gravity. This time will also be used to be prepared for the climbing expedition in terms of material inspection and checklist memorization. On Gusev Crater, a methane, water and oxygen production facility will be available. Therefore, the ship will be connected to those facilities and the only product from Earth that will be consumed is the food. Both ships have life support systems, thus the crew will be using both of them as a base.

D. The climbing expedition

The climbing expedition is the central part of this mission. It will be performed by four members of the crew. Around January 24^{th} 2041, the astro-biologist and the physician will stay together in one ship at the base in Gusev Crater while the rest of the crew will be on the second ship, also equipped with Life Support Systems, getting ready for the expedition. It has been decided to leave the surgeon at the base which may seem counter-intuitive. Mission design team has considered that in case a medical problem happens while the astronauts are climbing, it would not be possible to perform a surgery in the rovers. All the crew members will have a medical training enabling them to stabilize a patient who would have had injured himself. Therefore it has been decided that an injured crew member needing a surgery would have to wait until the crew is back at the base. It has been considered that it is safer to have the surgeon taking the least risk, in order to have him safe in case one of the crew member would have a long term affection or need of care, for example during the way back to Earth.

The mission is planed to last for 5 days but the crew will carry food, oxygen and water for 4 people for 14 days in order to have back-up, in case there is a problem during the expedition.

Mount Olympus is situated $3,600$ km away from Gusev Crater. The ship will be refueled with methane and oxygen and the vehicle will perform a "hop" maneuver and land on Mount Olympus, 10 km of altitude away from the top. The calculation related to this maneuver will be detailed on the Mars Operations report. From there, the 4 members of the crew will drive in 2 rovers up to 1 km of altitude from the top. From there, the commander and the tourist will start climbing by foot to the top while the two other members of the crew are following with the rovers for safety. The crew will be able to take some rest and sleep in the rovers as well. The crew chosen for the expedition is composed of two mechanical engineers and an electrical engineer, able to solve rovers failures. The rovers and the time of the different operations are detailed in the Mars Operations report. After 8 h of climbing by foot, the crew will reach the top on the 26^{th} of January 2041. The 4-people crew will then spend the night in the rovers before heading back.

They will then follow the same path of action to go down the Mount and back to Gusev Crater with a new "Hop" maneuver. The total time for the climbing expedition is 5 days.

A visual representation of the climbing phase is given in Fig. 11

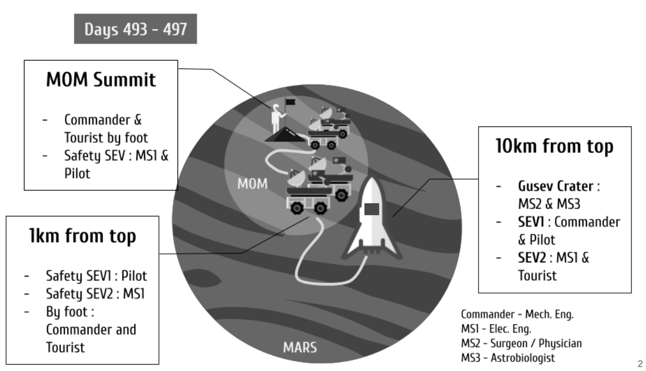

Figure 11. Mount Olympus Mom climbing Timeline

E. Martian experiment

Once all the crew is reunited in Gusev Crater, there will still be about 6 months before the launch window opens. This time will be dedicated to experiments for scientific research. Being on Mars is an incredible opportunity to get to discover more about the Martian geology as well as its atmosphere and the effect of reduced gravity on life. Those experiment will be done for private companies and public institutions and will be led by the astro-biologist specialist of the mission. This will be more thoroughly discussed in the Overall Coordination report.

F. Return journey

After 340 days on Mars, the crew will leave the planet after having re-filled the ships with water, oxygen and methane. The vehicles will take off from the crater, orbit Mars and then perform an escape burn in order to enter the return trajectory to Earth as described in Section III. The vehicles will have enough propellant to perform the take off, return trajectory, direct reentry on Earth atmosphere and landing. The consumption of food, oxygen and water will be the same as for the outward trip. The return trip will take 305 days and the crew will finally successfully arrive on the Earth surface around the 31^{st} of May 2041.

VII. OFF-NOMINAL CASES

Throughout the course of an interplanetary mission, the amount of potential setbacks are plentiful. One of the potential casualties is the harm space debris or micro-meteoroids can cause a spacecraft and the crew it is carrying. In order to minimize the potential of such a risk, a tracking system is needed. A tracking system that utilizes a sensor in order to detect incoming meteoroids or micro-meteoroids, then calculate if it is necessary to perform an emergency avoidance maneuver. This would allow the spacecraft to stay on its trajectory whilst still being able to perform small emergency maneuvers from potential threats. These maneuvers can be performed with the RCS thrusters as the needed ΔV is in the order of a few m/s if the debris are detected well in advance.

The ISS uses small thrusters in the "last minute" in order to correct its orbit. These are used 1.5 orbits before predicted collision, which can be approximated to 135 minutes before expected impact [7]. If the spacecraft were to use same safety margin in terms of time, as a micro-meteoroid travels on average at the speed of 10 km/s, it would require a tracking system that successfully detects micro-meteoroid at a considerable distance away from the spacecraft.

The DSN is used to keep track of any potential debris larger than a softball that could hit the ISS. As the DSN is located on earth, it could not be considered useful for this mission, because the time delay exceeds what is considered manageable. This puts the requirements on the spacecraft's tracking system on an un-achievable level as of today, mostly due to the large distance and high velocity of the micro-meteoroids.

Even if the spacecraft were to predict and avoid any potential collisions, protective shields are needed to ensure any unfortunate hazards. The shielding that has proven to be most efficient for the ISS is the Whipple Shield [9]. The Whipple shield utilizes a thin layer of material at a certain distance away from the targeted objective. It is used as a sacrificial layer, this layer of material is not expected to stop the incoming object. Instead, it breaks the material into several pieces and in that way diverging its kinetic energy into several different sources before impacting the spacecraft. This reduces the risk of an object penetrating the spacecraft and potentially causing a hazard. Different combinations of materials as well as the number of layers and distance between them can be used in order to offer different levels of protection. One of the primary motivations for using Whipple shield is its relative low weight, which is of great interest when it comes to designing a spacecraft.

Solid shields offers valid protections as well, but do not offer the same light weight properties as the Whipple shield does. The total weight can potentially be reduced by using light weight materials such as carbon fibre composites over materials similar to aluminum alloys. Kevlar offers a great strength-to-weight ratio and a high heat resistance which are two characteristic properties desired [10].

The solid shields using Kevlar is deemed more suitable for these type of missions; as it is easier to incorporate it into the fuselage and offer protection; than having different layers of shields at a certain distance outside the spacecraft. The Whipple shield is considered great for the ISS as the space station is in a stable orbit around earth, and not exposed to any large amount of forces for a short period of time. The Whipple shield's design would lead to a too awkward and unsuitable spacecraft with the purpose of conducting an interplanetary mission.

This off nominal case study leads to the conclusion that there is no current technology enabling to detect well in advance a debris coming to the spacecraft once outside Earth's Orbit. In LEO, debris bigger than 10 cm can be detected from Earth and can therefore be avoided in case they cross the vehicles paths when they are taking-off or orbiting earth during the refuelling period. Outside Earth's Orbit, meteoroid detection is almost impossible due to the high velocity of the spacecraft and the objects which would require detection from huge distances. Additionally, there is no planned future research aiming at developing better detection technologies. Luckily, the density of object present in deep space is really low, resulting in a very low probability of a collision with an object. This risk is considered acceptable for this mission. Thus, the vehicles won't be given additional shielding against collisions with extra-terrestrial meteoroids.

VIII. Conclusion

Climbing to the top of the highest mountain of the Solar System and planting an international flag, at an altitude of 21 km above Mars' sea level could potentially become a reality in the following decades. This project report, which is one of the five composing the blue team feasibility study of such a mission, explains how it could take place. The result is a 985 days mission starting in 2039, including 340 days on Mars. The mission would be achieved with two spaceships following a direct trajectory to reach Mars from Earth and return. The crew would be composed of six astronauts, including one paying member. Two rovers would be used from an altitude of 10 to 1 km from the top, and the last kilometer would be performed by foot by the Commander and the paying member of the crew.

Sufficient information and data have been provided in this study regarding the logistics and technical aspects, deeming this mission realistic in a 2040 time-frame.

References

[1] JPL Horizons Web-Interface, 2018.
[2] H. D. Curtis, *Orbital Mechanics for Engineering Students*, Elsevier, Fourth Edition, 2019
[3] T. Ishimatsu, J. Hoffman and Olivier d. Weck, *Interplanetary Trajectory Analysis for 2020-2040 Mars Missions including Venus Flyby Opportunities*, Department of Aeronautics and Astronautics, Massachusetts Institute of Technology, Cambridge, 2009
[4] J-M Salotti, *Simplified scenario for manned Mars missions*, Acta Astronautica, Volume 69, Issues 5–6, September–October 2011, Pages 266-279, 2011
[5] NASA Preserverance Communication, 2020.
[6] NASA What is the Deep Space Network?, 2020
[7] Emergency maneuver by ISS to avoid debris underlines why space traffic management is crucial, 2020
[8] ESA Blog, Time Delay Between Mars and Earth, 2012
[9] Shielding the International Space Station, 1997
[10] What is Kevlar? – Kevlar Uses, properties and processing, 2020