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ÚSTAV JAZYKŮ

SPACE EXPLORATION OF MARS

VESMÍRNÝ PRŮZKUM MARSU

BACHELOR'S THESIS

BAKALÁŘSKÁ PRÁCE

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TITLE OF THESIS:
Space Exploration of Mars

INSTRUCTION:

Space exploration of Mars, often referred to as the "Red Planet" has been rapidly growing in recent times. Initially spurred on by NASA by such programs as Mars Exploration Program (from 1993) and Mars 2020, the planet has had rovers and helicopters gathering evidence from its surface. But in recent years even private initiatives, such as Elon's Musk SpaceX, have begun planning to launch missions to Mars in the near future. The aim of the semester project is to survey the above programs, focusing on recent ones in the 21st century, stating their goals and the technology used. The bachelor thesis will have a greater analysis and a more in-depth discussion of human space travel to Mars.

RECOMMENDED LITERATURE:

Larry Crumpler, Mission to Mars: A New Era of Rover and Spacecraft Discovery on the Red Planet, Harper Ollins Publishers, 2021.336 pp.
https://www.perlego.com/book/2294389/missions-to-mars-a-new-era-of-rover-andspacecraft-discovery-on-the-red-planet-pdf
JPL's Plan for the Next Mars Helicopter, IEEE Spectrum, at https://spectrum.ieee.org/the-next-mars-helicopter Mars Perseverance Press Kit, NASA, January 2021 at
https://www.jpl.nasa.gov/news/press_kits/mars_2020/download/mars_2020_landing_press_kit.pdf

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Abstract

This bachelor thesis summarises past and present missions to Mars and lists the discoveries, achievements and technologies used during each mission. The first chapter focuses on the first reconnaissance missions of the Soviet Union and the United States during the Cold War and describes the important achievements of each mission. Furthermore, this thesis discusses rovers such as Opportunity, Spirit, Curiosity and also Perseverance, which have been designed for mobile exploration of the planet's surface. The last part of this thesis explores the possibility of sending a human crew to this planet, the construction of habitats and the actual journey between Earth and Mars. This chapter also outlines the health risks and various problems that a crew would face during such a mission.

Keywords

Mars, Red Planet, space exploration, Space, habitat, Mars 2020, SpaceX, NASA, Curiosity, Pathfinder, Opportunity, space travel,

Abstrakt:

Tato bakalářská práce shrnuje minulé a současné mise k Marsu a uvádí objevy, úspěchy a technologie použité během jednotlivých misí. První kapitola se zaměřuje na první průzkumné mise Sovětského svazu a Spojených států během studené války a popisuje důležité úspěchy jednotlivých misí. Dále tato práce pojednává o roverech, jako jsou Opportunity, Spirit, Curiosity a také oPerseverance, které byly navrženy pro mobilní průzkum povrchu planety. Poslední část této práce se zabývá možností vyslání lidské posádky na tuto planetu, stavbou habitatů a samotnou cestou mezi Zemí a Marsem. V této kapitole jsou také nastíněna zdravotní rizika a různé problémy, kterým by posádka během takové mise musela čelit.

Klíčová slova:

Mars, Rudá Planeta, vesmírný průzkum, vesmír, habitat, Mars 2020, SpaceX, NASA, Curiosity, Pathfinder, Opportunity, vesmírné cestování

VÁLEK, Jiří. *Vesmírný průzkum Marsu.* Brno, 2023. Dostupné také z: https://www.vut.cz/studenti/zav-prace/detail/151512. Bakalářská práce. Vysoké učení technické v Brně, Fakulta elektrotechniky a komunikačních technologií, Ústav jazyků. Vedoucí práce M.A. Kenneth Froehling.

Prohlášení

Prohlašuji, že svou bakalářskou práci na téma Vesmírný průzkum Marsu jsem vypracoval samostatně pod vedením vedoucího bakalářské práce a s použitím odborné literatury a dalších informačních zdrojů, které jsou všechny citovány v práci a uvedeny v seznamu literatury na konci práce.

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V Brně dne …………..……………… …………..………………

Jiří Válek

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Table of Content

1. Introduction

One of the brightest objects visible to the unaided eye in the night sky is Mars. This planet has attracted the curiosity of numerous renowned and well-known astronomers, including Galileo Galilei and Nostradamus. Humankind has always been fascinated by the night sky and has searched for something in it. From simply gazing at the sky, we have progressed to a period when several space programs are active and interest in near-space objects is on the rise.

The first programs during the Cold War sparked a major interest in space exploration. The Apollo program, with its manned journey to the moon, was one of NASA's most significant achievements, which inspired many to start exploring other space objects and planets. Therefore, The Soviet Union and the USA, for various reasons, be it political or scientific, raced to explore our solar system, including the planet Mars. Dozens of probes have been sent to the Red Planet under various programs, but not all of them managed to successfully finish their mission. Among the most successful programs of that time was the US Mariner program.

The technologies and research equipment used in space exploration is constantly evolving. From probes designed to take just a few pictures as they fly past the planet, we have moved on to autonomous rovers moving across the deserts and rocky terrain of Mars. Opportunity and Curiosity, which are the two rovers, have exceeded expectations and continued to operate beyond their planned original lifetime. Insight has become the first “Martian” helicopter ever to fly over the surface of Mars. Every new exploration program we send to this planet makes use of more advanced, precise, and efficient technology than before.

Mars is the second closest planet to Earth, but it could still be considered an unexplored place that could hold many mysteries which are waiting to be discovered. Despite NASA's long and active exploration, other companies such as SpaceX and Europe's ESA are slowly starting to join in with their own missions.

This bachelor’s thesis provides an overview and comparison of the results of these missions including the most important discoveries and information about the missions and also considers both the successes and failures of these missions. The various exploration programs of the different companies involved in these journeys are also introduced. The last chapter provides a description of possible future missions and upcoming programs that may take place in the near future, including possible manned missions and the possible risks a human crew would face while staying on the Red Planet.

2. Early Missions

The very first person to probably observe Mars was Aristotle. He made his observation between 375-356 BC when the planet Mars was passing behind the Moon. The sighting of Mars was not recorded until Galileo Galilei saw Mars with his telescope in 1609. Unfortunately, it failed to capture any details of the planet's surface due to the technology of the time. These observations were the first confirmation that the planet Mars was somewhere around (Snyder, 2001).

The recent interest in Mars dates to the 1960s. It was the Cold War that kicked off a much larger effort to explore and reach Mars in the 60s and 70s. The United States and The Soviet Union planned many ambitious space programs with the intention to show superiority over each other. This Era is sometimes referred to as “The Space Race” because the Americans and Soviets literally competed to see who would be more successful in space exploration, thus demonstrating their technological, political, and military superiority. (History.com Editors, 2010)

2.1.Soviet Mars program

The Soviets, after losing the “The Race for the Moon”, focused on Mars, which at that time was a completely unexplored planet. So Soviet scientists launched many spacecraft to explore and gain new knowledge before the West. The Soviet space program was conceived as a project to partially demonstrate superiority over other countries. The very first missions launched various spy and reconnaissance satellites into orbit. Among these programs, however, was one that will always be etched in human history. In 1961, a Soviet team of scientists succeeded in sending the first man into space, Yuri Gagarin. As part of his mission, he managed to orbit the Earth and land back on Earth in the Vostok 1 spacecraft. (Messier, 1996)

“There had been interest in Mars in Soviet culture dating back to the early 20th century. A whole generation grew up learning about Mars through popular science fiction novels and movies, such as Sergei Korolev, who headed the Mars program in the early 1960s. So, Mars was a natural objective. They even funded studies for human missions to Mars, although these were downgraded by the late 1960s” (Hill, 2021). There is no doubt that these early successes influenced many writers to start writing their books about space exploration. There were various science fiction films and novels that raised public interest and awareness of space exploration. After these early space successes, the idea of exploring our second closest planet, Mars, began to emerge.

Mars 1M No.1 and Mars 1M No.2 were the first of a series of Soviet probes to go to the Red Planet. Their launches took place in October 1960. Their goal was to measure and monitor the space environment along the way to Mars. The probes were identical and carried the same equipment and were assembled by the OKB-1 design bureau. The scientific equipment included: a beam-mounted magnetometer, a cosmic ray counter, and a radiometer. The Molniya (R-7 8K78) was used as a carrier rocket. The 1M No.1 spacecraft failed on its launch due to a malfunction on the carrier rocket. The third and fourth stages along with the interplanetary probe burned up in the atmosphere over eastern Siberia. similar scenario applied to the other probe, the launch rocket with the satellite burned up in the Earth's atmosphere. The cause of the failure was the freezing of kerosene in the transport pipe before the actual rocket launch. Both projects were major failures for the Soviet Union (Havlíček, 2003).

Missions 2M No. 521 and 2M No. 522 launched in 1969, also failed. The Zonde 2, which attempted to fly by Mars, can be considered at least a partial success because it managed to get beyond Earth’s orbit. Although it was an initial success, the probe lost one of its two solar panels and therefore operated at only half power. Communication with the probe was lost less than six months after launch. The 1960s were not the best period for the Soviet Union at all. "The Soviets launched at least seven missions to Mars during the 1960s. “They all failed. The vehicles were either destroyed during launch, were unable to leave Earth orbit, or suffered catastrophic failures en route" (Messier, 1996)

The Mars 1-7 space programs were the first to have any success, apart from Zonde 2. The Mars 1 probe could be only considered partly successful because, like its predecessors, it lost communications, but it managed to leave Earth’s orbit and head for the planet Mars. It was supposed to fly past the planet and send atmospheric data back to Earth for analysis (Perminov, 1999).

In 1971, the USSR decided to launch the Mars 4M mission, which consisted of a pair of probes, Mars 3, and Mars 2. The rockets used were Proton-K, which were much more powerful and reliable than their predecessor Molniya Rockets. Both probes were built by the NPO Lavochkin company and consisted of an orbiter and a lander. The main purpose of Lander was to take images of the Martian Surface and determine the probable temperature on Mars, for further study of topography, composition, and chemical components of Martian soil and atmosphere. Lander was equipped with a mass spectrometer and 360° camera. The lander was protected in a 2.9m spherical landing capsuled. The landing system consisted of a parachute and retrorockets. Unfortunately, the landing had to be postponed due to a severe dust storm that was currently sweeping across the planet's surface. In both cases, the lander failed eventually. Mars 2 successfully orbited the planet, but the lander malfunctioned while landing and crashed at high speed into the Martian surface. The Mars 3 lander, which managed to land successfully, became the first human machine on the surface of Mars. It transmitted from the surface for only 14.2 seconds until the connection was broken (Krebs G. D., 2023b). The image in Figure 1 was taken by Mars 3 during its landing on Mars at 45°S, 202°E, in Ptolemais Crater. This image is sometimes referred to as “The first image taken from the Surface of Mars.” (Crumpler, 2021, pp. 34-35)

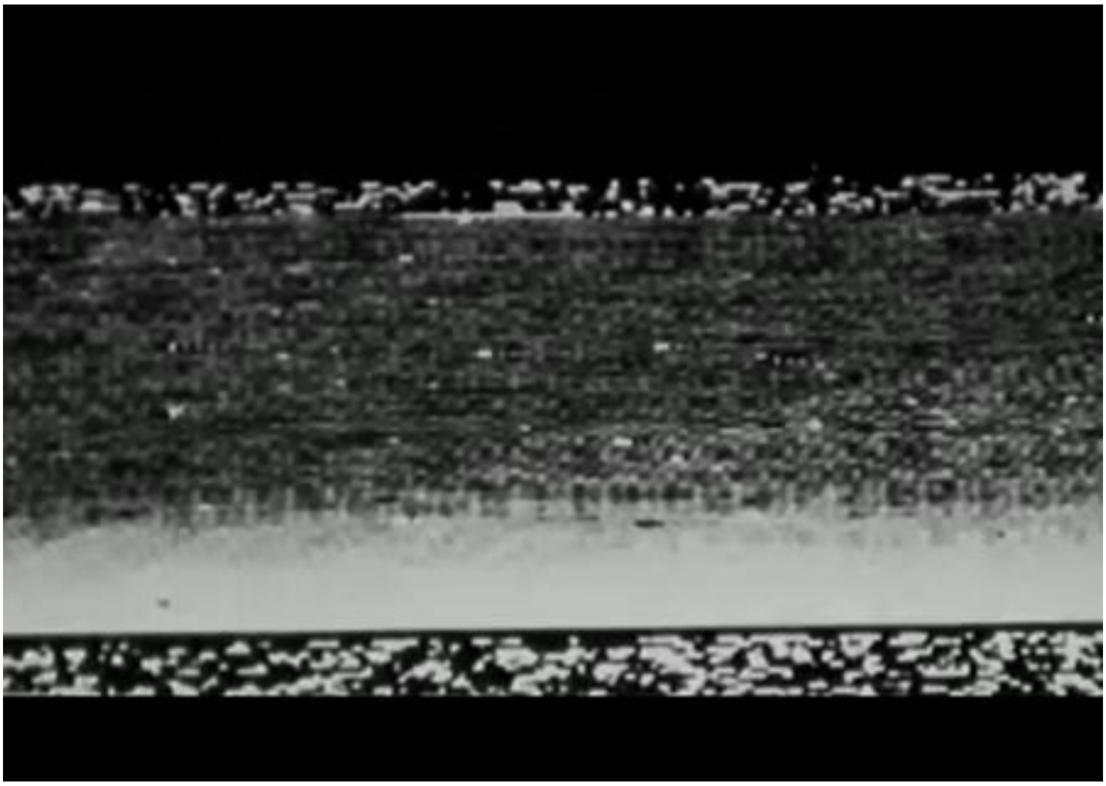

Figure 1: The First Image Taken and Transmitted from the Surface of Mars

Soviet scientists launched Mars 4, 5, and 7 spacecraft in 1973. Both Mars 4 and Mars 5 were almost identical and weighed 3,440 kg completely fuelled. Both probes featured an electrostatic analyser, several photometers, polarimeters, magnetometers, and a 256-channel Nal gamma scintillation spectrometer with charged particle repulsion. Its main purpose was to measure the spectral composition of the gamma rays of Mars. "The gamma-ray spectrometers on Mars 4 and 5 detected an average cosmic gamma-ray background flux density 1.85e4 quanta/m²/s. Mars 5 has been very successful in its primary study of Mars." (Johnson, 1979, pp. 198-202).

Mars 4 reached the red planet, but due to a critical retro-engine malfunction, failed to maintain the orbit and burned up in the Martian atmosphere. The probe was able to gather and send some data back to Earth before it malfunctioned. (Perminov, 1999, pp. 64-66)

Mars 5 successfully survived in orbit around Mars for several weeks and then also suddenly failed. The spacecraft sent 180 photographic images back to Earth, but only forty-three were of usable quality. The gamma-ray spectrometer was able to measure the uranium, potassium, and thorium present on the surface of Mars. The lander's radiometer measured a temperature range of 272 K (-1.15 °C) to 230 K (-43.15 °C) during the day and 200 K (-73.15 °C) at night. (Williams D. R., 2022b)

Mars 6 used a Proton SL-12/D-1-e rocket for lift-off and arrived in orbit of Mars in February 1974. The descent module was successfully separated and landed on the surface. The data transmission lasted for 224 seconds when suddenly the transmission malfunctioned. The acquired data were used to determine the density of the atmosphere between altitudes of 82 and 12 km and the structure of the troposphere. The measured surface pressure was six mb. The probe measured several times higher percentage of water vapours in the atmosphere than was previously detected. Not all of the acquired data was sent back because the probe failed before completing the data transmission was completed. (Williams D. R., Mars 6, 2022c). The ionosphere's existence at night-time in altitudes of 110 km from Mars' surface was confirmed. The measured electron density was up to 4,600 electrons per cubic cm. The overall data results were identical to those of the Mars 5 mission (Grayzeck, 2008).

A Proton-K/D booster rocket launched Mars 7 into Earth orbit and put it on a course for the red planet. A malfunction in the computer unit that controlled the altitude and entry vehicle caused the lander to separate prematurely and miss the planet by 1,300 km. The malfunction must have occurred during the long journey to the planet (Ivankov, 2022).

2.2.NASA’s program

Unlike the Soviet programs, the American ones were far more successful. A series of exploration missions called Mariner (numbered 1 to 10), were among the greatest successes of the early NASA space program. In all, ten robotic interplanetary probes were designed and built to explore the inner solar system. These programs were to visit not only the planet Mars but also Venus and Mercury. The targets of Mariners 1,2,5 and 10 were the planets, Venus, and Mercury. Out of a total of ten probes built, seven missions were successful. The other three were lost due to multiple failures. The first Mariner (Mariner 1), which headed for Venus, failed after 294.5 seconds due to errors in the guidance and communication system. The errors were caused due to a typographical error in the specification of the handwritten guide equations, which were later coded by use of the computer. The Program Mariner chapter details the reasons why the other two Mariners, which were bound for Mars, failed. (Siddiqi, 2018, pp. 26-27)

2.2.1. Atlas rockets

The Jet Propulsion Laboratory (JPL) of NASA was charged with creating and putting together interplanetary spacecraft, which led to the start of the Mariner program in 1960. An Atlas rocket with an Agena or Centaur upper stage was designed to take the probes on and beyond Earth’s orbit. At first, Atlas rockets were intended to be intercontinental ballistic missiles, but their purpose changed with the coming space programs. Atlas A, B, and C were only test versions, and they were never put into operation or active service. The liquid-fuelled engine produced a thrust of 1,600 kilonewtons, radio-inertial guided and with a range of 12,000 km. The Atlas E and F served primarily as nuclear warhead launchers but were retired from service after the development of the Minuteman ICBM (intercontinental ballistic missile). Atlas rockets have consisted of two boosters and sustainer engines. Boosters could fire approximately for 150 seconds of flight and then had to be jettisoned. The Sustainer could run up until the rocket reached the orbital velocity. Atlas first stage rockets in the combination of Atla-Centaur upper stage run on kerosene and the second stage (Centaur) run on liquid hydrogen. These rockets went through many modernisations and were replaced by Atlas I and II. In the year 2000, the Atlas III was introduced, which used the RD-180 (Russian rocket engine) as the first stage. The Atlas V, which also uses the RD-180 engine, is the most recently developed and introduced rocket from the Atlas Family (T. Editors of Encyclopaedia, 2013).

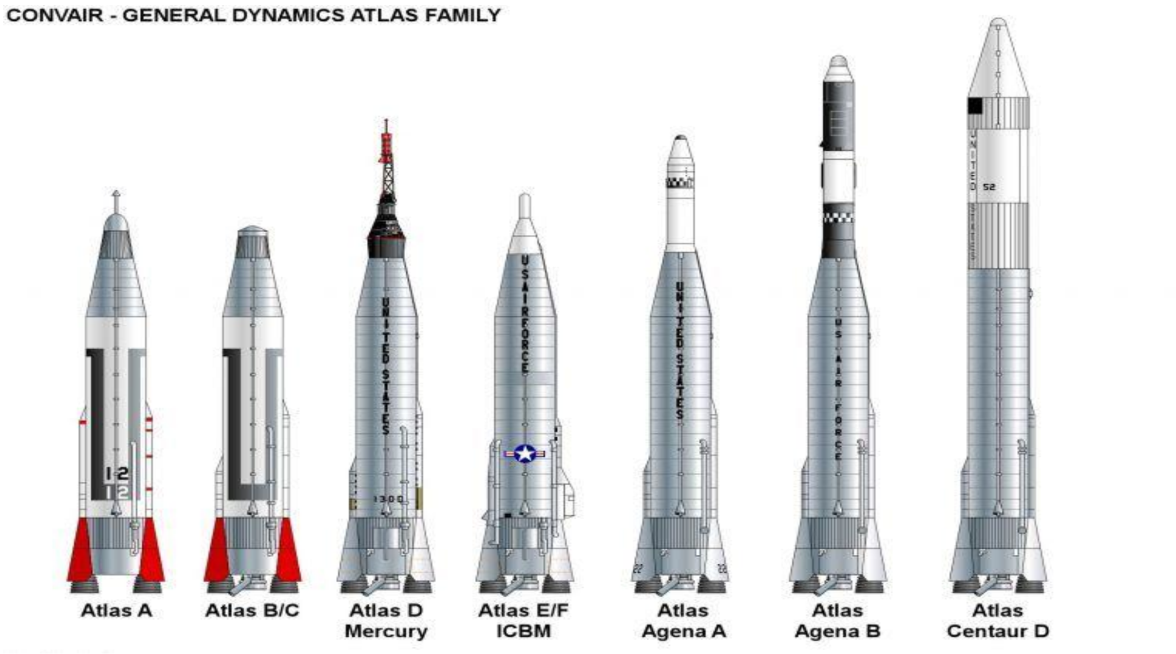

Figure 2: Atlas Family tree

2.2.2. Program Mariner

Almost all the Mariner probes were relatively light as they weighed less than half a tonne, except for Mariner 9, which weighed 974 kg. Each spacecraft had to carry solar panels that were used to power scientific instruments on board the spacecraft. The probes included a dish antenna for communication and data transmission. Probes were completed within a year or two (Jet Propulsion Laboratory, 2001).

The Atlas rockets were still "untested" launch vehicles at the time, so each probe was always launched separately to avoid losing both probes in the event of a launch failure. Loss of probes occurred in the Mariner 1,3, and 8 programs, but their backup versions were successful (Jet Propulsion Laboratory, 2001).

The Mariners 3 and 4 were almost identical and both headed for planet Mars. A total of three probes were constructed, one backup and two others that were sent. Mariner 3 was powered by batteries that were charged by 28,244 solar cells mounted on four sides of the spacecraft. Together, the cells generated up to 700 W of electrical power. The probe weighed 260 kg and was designed to take measurements above Mars, take photographs of the planet's surface, and send all obtained information back to Earth for analysis. The probe was designed to measure charged particles created by the solar wind. The Geiger-Mueller tube along with the ionization chamber was designed to measure and determine the number of charged particles that were causing the ionization (Krebs G. D., 2017). The Cosmic Ray Telescope was used for the detection of protons in three energy ranges. A low-gain omnidirectional antenna and a high-gain parabolic antenna with a diameter of 116.8 cm were used for communication. Also, cameras, infrared radiometer, ultraviolet spectrometer, and infrared interferometer were scientific instruments on board the probe. Atlas LV-3 Agena-D rocket was used as the launch vehicle for Mariner 3 and 4. (Marspedia, 2019)

Mariner 3 successfully took off from the surface in November 1964. After passing through the Earth's atmosphere and setting the spacecraft on its trajectory, instruments indicated that the shroud protecting the spacecraft during its passage through the atmosphere had failed to drop. Despite all rescue attempts to drop the cover, ground control failed to save the spacecraft and after 8 hours its batteries died (Krebs G. D., 2017).

After a detailed examination of the Mariner 3 malfunction, the JPL engineering team determined that the cause of the failure was a spring-loaded separation mechanism that had become entangled and was not allowing the module's housing to separate properly. This failure was caused by a large pressure differential between the inner and outer portions of the housing. The new cover that was developed no longer had this problem but was considerably heavier (Krebs G. D., 2017).

In November 1964, the Mariner 4 was successfully launched. The probe arrived at its Destination in July 1965 and began mapping the Martian surface with its cameras. The images taken, covered a discontinuous strip of the Martian surface starting at 40 N, 170 E and ending at 50 N, 255 E. Together, the captured images formed about 1% of the planet's surface. All the captured images were sent back to Earth twice to prevent data corruption or loss due to errors. Communication with the probe was terminated on 21 December 1967 (Siddiqi, 2018, pp. 41-43; NASA, 1967, pp. 150-185). Layout of Mariner 4 instruments is shown in Figure 3.

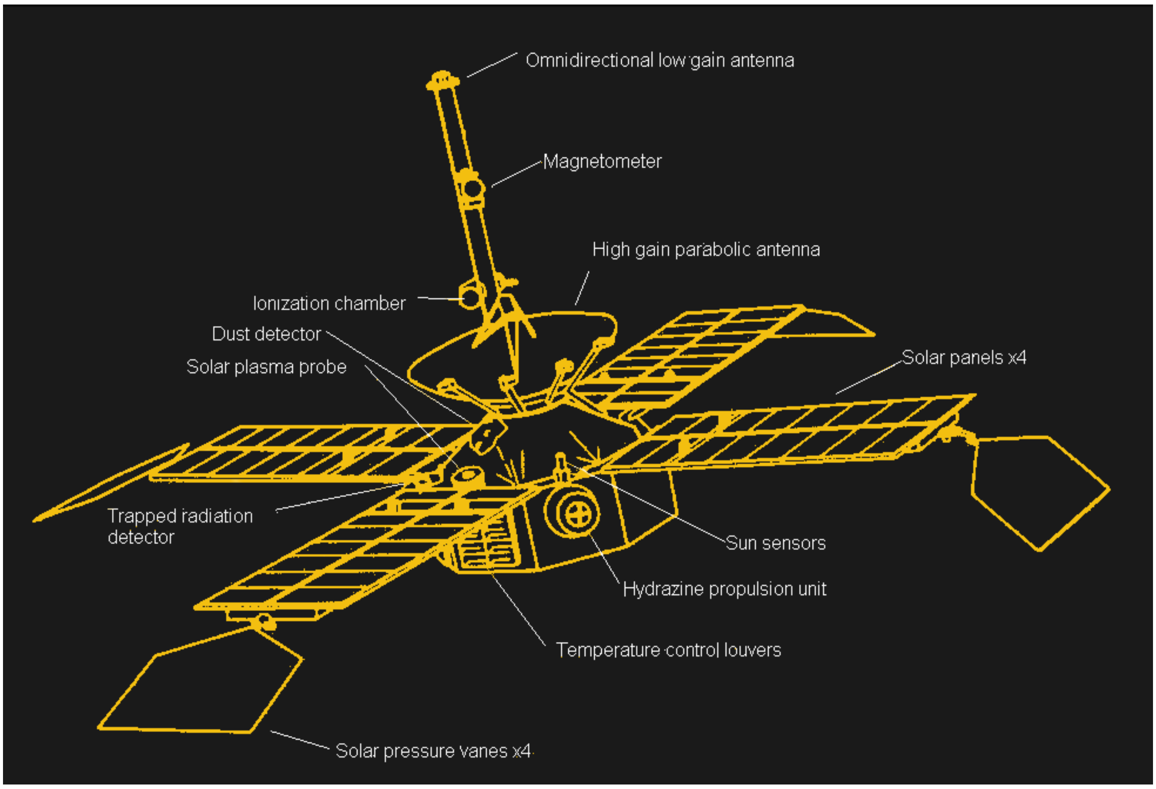

Figure 3: Mariner 4 scheme

Several scientists had not expected Mariner 4 to find such a high number of craters on the surface. The size of the found craters ranged from 5 to 150 kilometres. The probe verified that the planet's magnetic field is weak, permitting easy passage of solar radiation. The measured air pressure was between 4.1 and 7.0 mbar (Marspedia, 2019). The "Mariner" crater, which bears the probe's name, is depicted in Figure 4.

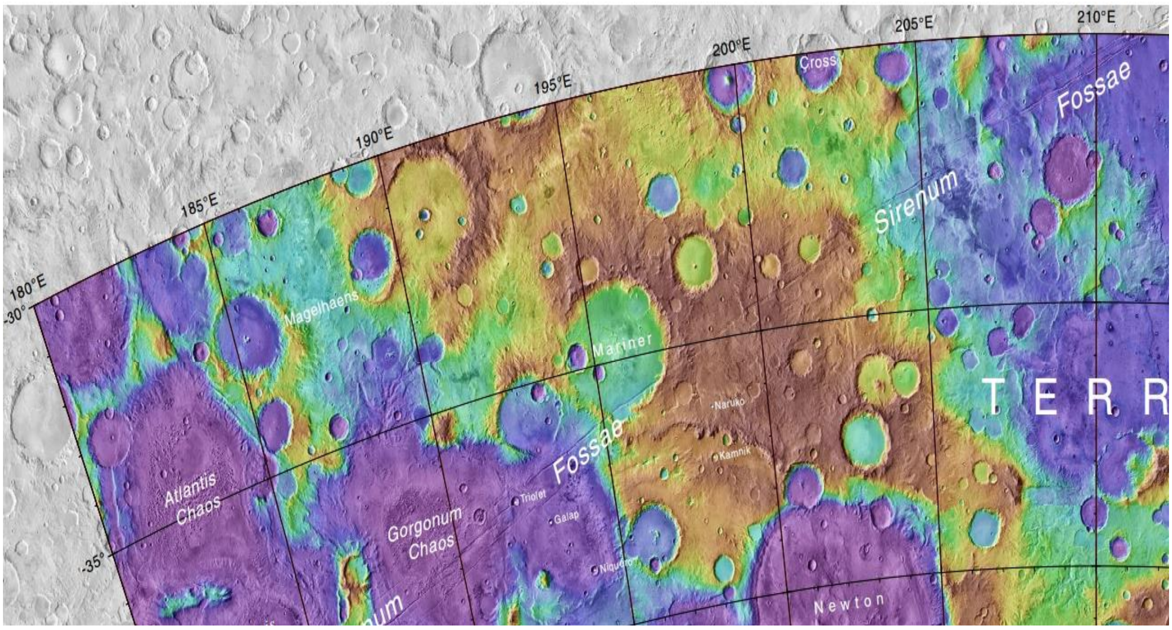

Figure 4: Map showing The Mariner Crater

Mariners 6 and 7 were identical and their design was based on their predecessors. Their main objective was to further explore the Martian surface in close flybys over the equator and southern hemisphere of Mars. The probes were carried on their intended trajectory to the planet by an Atlas-Centaur rocket that launched from the Eastern Test Range in Florida. Together, the two probes managed to take nearly 201 images, which together represented 20% of the Martian surface. These images helped to unravel the mystery of dark formations, that Earth astronomers observed before. These dark formations as it was discovered were ancient water channels. Probes captured craters, valleys, and many giant volcanoes on the surface. The images taken can be seen in Figure 5, which shows a map of Mars with the areas corresponding to these images highlighted. The equipment on both probes was very similar to their predecessor, Mariner 4. The equipment included an infrared radiometer, an ultraviolet spectroscope, and narrow-angle, and wide-angle cameras. The observations and data obtained were very ground-breaking. The mission was able to detect residual water present on the surface of Mars (Pyle, 2012, pp. 61-66). Studies and measurements of the atmosphere showed that the Martian atmosphere is composed primarily of carbon dioxide. The total cost of both missions was $148 million. (Mark, 2019)

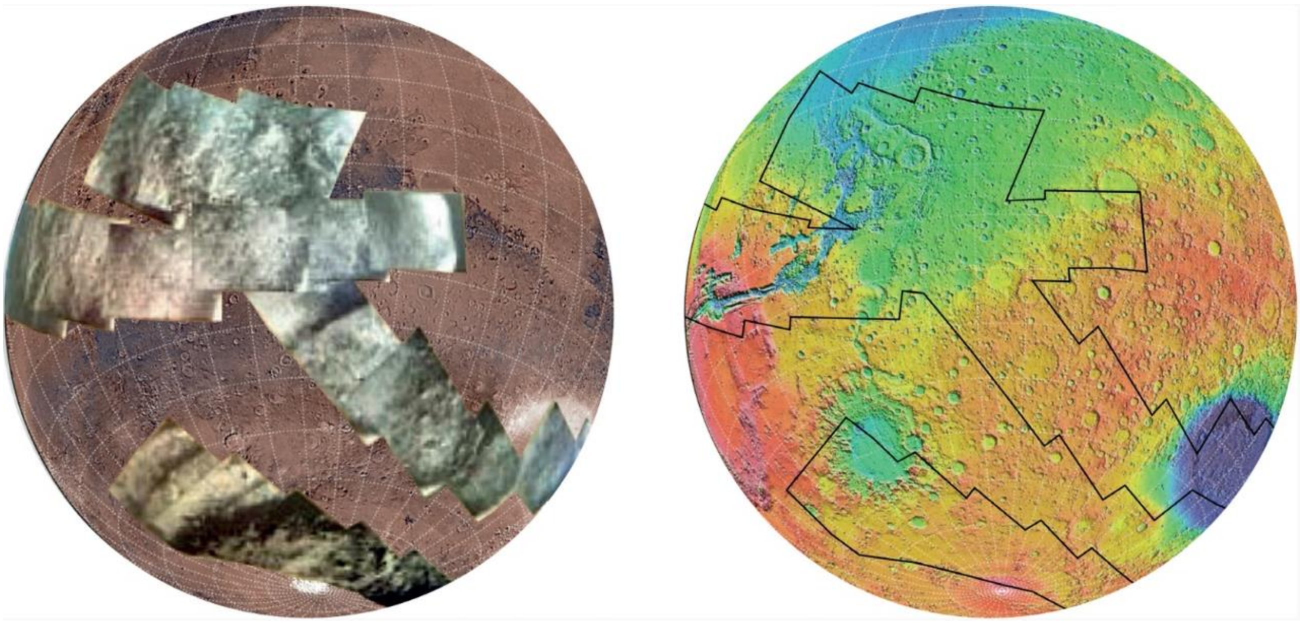

Figure 5: Images across Mars during a flybys in 1969

Mariner 8 was the first pair of probes that were launched in 1971 from Cape Canaveral, Florida. The mission intended to explore the dynamic and physical characteristics of the planet and search for areas that could support life. Another important goal was surface mapping. The data collected was to help select the best landing site for Viking 1 lander (Siddiqi, 2018, pp. 87-88).

The Atlas-Centaur SLV-3C booster (AC-24) was selected as the launch vehicle (Krebs G. D., 2019). The spacecraft was launched on May 9, 1971, from Cape Canaveral, Florida. The first stage ignition, which lasted two and a half minutes, went well along with the ignition of the two Centaur engines. Nevertheless, the Centaur module control unit malfunctioned a short while afterwards. The control over the rocket was lost at a height of 160 kilometres. The lander tilted and re-entered the Earth's atmosphere and the mission ended in failure (Wilford, 1971).

The second one of the pair was Mariner 9. The probe managed to get to the orbit of Mars just a few weeks before Soviet probes Mars 3 and Mars 2. At the time of arrival, there was a huge sandstorm on the planet's surface, so the mission was suspended until the sandstorm passed and the dust from it settled. The primary mission goal of Mariner 9 was to study temporal changes in the atmosphere and on the surface of Mars, along with some tasks inherited from the failed Mariner 8. When the sandstorm on the surface subsided, Orbiter began taking detailed images of the planet's surface. Among the many images taken by the orbiter was a picture of three supervolcanoes in a row. One of them was Olympus Mons, which is considered the highest-known peak in our solar system. A total of 7,329 images were taken, covering 100% of the planet's surface. Mariner 9 also captured Mars' moons Phobos and Deimos. A variety of data was sent back to Earth, including the composition, density, and temperature of the atmosphere of Mars, as well as the measured levels of gravity. The spacecraft was shut down on October 27, 1972, due to the depletion of the gas supply used to correct the orbiter's path. Mariner 9 is left in orbit, where it should last approximately 50 years, and then fell into the Martian atmosphere (Krebs G. D., 2019). A picture of Mariner 9 can be found on page 21 as Figure 6.

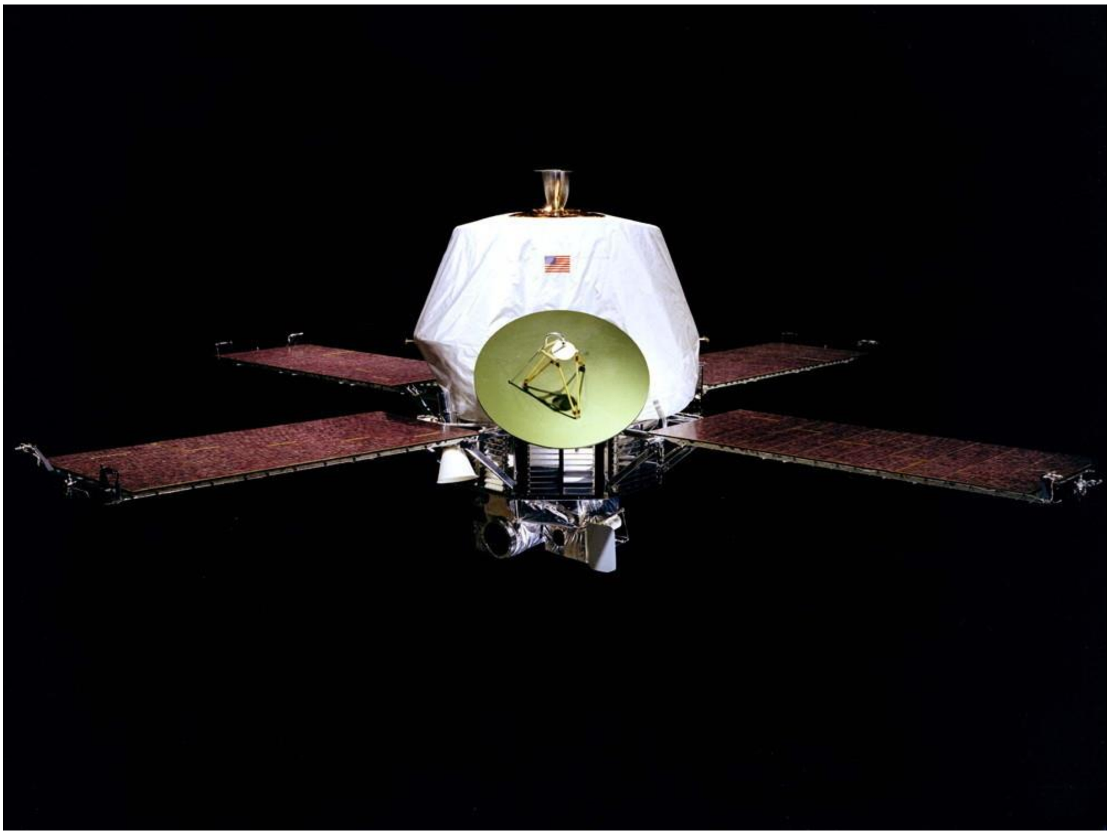

Figure 6: Mariner 9

2.2.3. Viking 1 and 2

In 1975, another NASA program called Viking was launched. It consisted of the Viking 1 and Viking 2 missions, and each mission included an orbiter and lander. The main objective of the mission was to obtain high-quality images of the planet's surface and make a series of measurements of the temperature and environment on the surface, also investigate the composition of the soil with the lander's scientific instruments. The orbiter intended to serve as a communication hub between the lander and flight control on Earth but also had to perform its own research tasks. The duration of the mission was planned for 90 days after landing, but both programs managed to beat that by several years.

The orbiter was partly based on the Mariner 9, with a 2.5-meter octagonal shape. Titan IIIE rocket with Centaur upper stage was chosen as the launch vehicle. The total weight of the orbiter was 1,445kg including propellants for attitude control. Solar panels were mounted on each of its four sides. A total of eight solar panels, consisting of 34,800 solar cells, served as the power source. These cells could produce up to 620 watts in Mars orbit. The control was provided by two general-purpose onboard computers which encoded the received commands in the subsystem. The commands could be executed immediately or stored in memory. The acquired data was stored on two eight-track digital tape recorders that could store up to 640 million bits. The orbiter communicated with the ground using a two-way, high-speed S-band radio link. This communication was provided by a steerable 1.5-meter high-gain antenna or a low-gain omnidirectional antenna, which was more likely to be used for near-Earth communications (Williams D. R., 2022a).

The landing module was in the shape of a hexagon with alternating long sides and a total weight of 657 kg. The lander stood on three 1.3 meters long legs, which were attached to the short-side bottom corners. The lander was sealed by bioshield in a form of a pressurized cocoon to prevent possible biological contamination of Mars by microbes from Earth. The contamination of Mars can seriously affect the measurements on the planet. This bioshield had a diameter of 3.7 meters and was made from coated, 0.13 millimetres of thin woven fibreglass. The whole Bioshield was supported by an aluminium structure. The overall shape of the bioshield resembled an egg (NASA, 1988). The lander was powered by two SNAP 19-style, radioisotope thermal generators with plutonium-238 and eight ampere-hour nickel-cadmium rechargeable accumulators. the reactor weighed 13.6kg and could generate a continuous power of 30W at 4.4V. The thrusters were controlled by an inertial reference unit that responded to data from four gyroscopes and a radar altimeter to control descent and movement over Mars. The Lander communicated using a dual-axis parabolic antenna (two TWTA transmitters) and a low-gain omnidirectional S-band antenna, which allowed Lander-Orbiter and Lander-Earth communication. The received data and instructions were stored on a 40 Mb tape recorder. The main instruments were attached to the top of the module. These instruments could measure meteorology, seismology, and magnetic properties. On one side of a lander was a moveable arm with a magnet collection head, and a temperature and wind sensor. Other equipment on the module included a seismometer, 360° camera, X-ray fluorescence spectrometer, pressure sensor, and instruments to detect life in the Martian soil (Williams D. R., 2022f).

Viking 1 and Viking 2 were launched a few weeks apart in 1975 from Cape Canaveral, Florida. Spacecraft arrived at Mars in 1976 and after orbiting for a few months, a NASA scientific team selected a landing site for both Viking landers. Chryse Planitia (22.27°N, 312.05°E) was chosen as the landing site for Lander Viking 1, and Utopia Planitia (47.64°N, 134.29°E) for Viking 2. Viking 1 was the first lander to successfully land and operate on Mars' surface. The Landing was accomplished by the 38 centimetres of mortar with a packed parachute inside. The 50 kilograms Dacron polyester parachute had a diameter of 16 meters and was attached to the lander by 30 metres long suspension line after the ejection from the mortar. The descent of the lander was controlled by a computer, which executed entry commands in response to radar altimeter data (NASA, 1988).

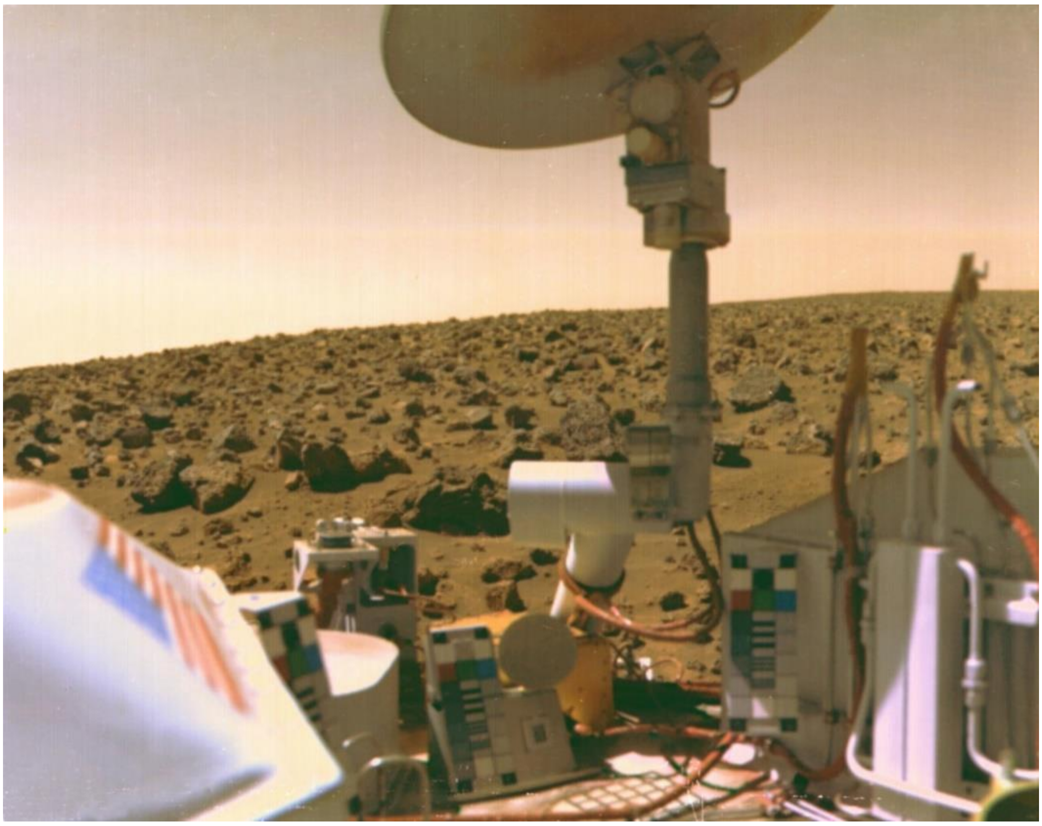

Figure 7: Viking 2 Lander on the surface of Mars

Figure 7 shows the Martian rocky landscape and the small, coloured squares on the lander used for adjustment and correction of the colours of the 360° Cameras.

Lander found no signs of organic molecules or organisms but managed to analyse the composition of the Martian atmosphere and soil. The Martian soil contained trace elements that had never been seen before, including mysterious chemical activity in the soil of the planet. Lander also found that Martian winds generally blow more slowly than scientists had previously assumed. The orbiter cameras observed new and often puzzling terrain and provided clearer detail on known places. The greatest concentration of water vapour in the atmosphere was found in the region nearest to the north polar cap in midsummer. Thus, the permanent north cap is water ice, the southern cap probably retains some carbon dioxide ice through the summer. Photographs from the landers and orbiters surpassed expectations in quality and quantity. The total number of images exceeded 4,500 from the landers and 52,000 from the orbiters (NASA, 1988).

3. The Phobos program

The Phobos program was conducted by the Soviets and consisted of two probes (Phobos 1 and Phobos 2). The main goal of this program was to explore two moons of the planet Mars called Phobos and Deimos. These two moons were given their names after the Greek demigod brothers and sons of Ares (the God of War). In Roman mythology, Ares is known as Mars. In Greek legends, Deimos and Phobos accompany their father Ares into several battles. This naming of two moons in contrast to the name of a planet is not particularly unusual because many other space bodies in our solar system also bear the names of mythical creatures or ancient gods.

One of the main objectives of the mission was observing the Sun on the journey to the Phobos by using the Terek telescope (Phobos 1). Other main goals of the mission included the study of the surface and atmosphere of Mars and the determination of the composition of Phobos' surface (Zak, 2021).

Both probes were nearly identical and carried approximately 25 scientific instruments, including a small surface station called DAS, with a seismometer, magnetometer, X-ray fluorescence spectrometer and penetrator. The pressurized toroidal electronics section and a modular cylindrical experiment section made up the spacecraft's main body. Four spherical-shaped tanks filled with hydrazine used for attitude control were attached to the bottom side. Twenty-four 50N and four 10N thrusters were mounted on the spherical tanks. Solar panels and other additional thrusters were attached to the spacecraft's main body. Proton and Alpha Particle Spectrometer, Energy, Mass, and Charge Spectrometer, Gamma Ray Emission Spectrometer, Secondary Ion Mass Analyzer, Infrared Spectrometers, and Video spectrometric System are one of many scientific which were parts of the probes. Figure 8 on page 26 shows what the Phobos 1 probe looked like. The solar panels, the four hydrazine tanks, as well as the other equipment of this probe can be seen in this picture.

Phobos 1 was launched in July of 1988 from Baikonur Cosmodrome, but during the journey, a faulty command was sent, which caused the deactivation of the attitude thrusters. The solar panels on the probe were facing the wrong direction because the spacecraft was unable to maintain its lock on the Sun. This issue led to the shutdown of the whole spacecraft, due to the depletion of batteries (Hamilton, n.d.). In addition to the common scientific instruments, Phobos 1 carried a carried Neutron Detector (IPNM) and Solar Telescope/Coronograph (TEREK) (Zak, 2021).

Phobos 2 was also launched in July of 1988 and collected data on the Sun throughout its journey. It also carried a lander, which was called The Hopper and was designed for surface measurements. This probe stood on spring legs, which enables the probe to perform up to 10 hops on the surface. It carried a dynamometer, magnetometer, gravimeter, penetrometer, and X-ray fluorescence spectrometer and was powered by batteries. The spacecraft was about 50 meters from the surface of the moon Phobos when it was about to release two landers. Unfortunately, contact with the spacecraft was lost due to a problem with the onboard computer. The Phobos 2 also carried a few different scientific instruments than Phobos 1, like Scanning Infrared Radiometer, and Energetic Particles detector (Krebs G. D., 2023a).

The USSR viewed the Phobos program as a failure. However, this effort contributed to support the hypothesis that Martian water was carried away by solar winds because the planet's magnetic field is weak (Zelenyi, Zakhov, & Polischuk, 2010).

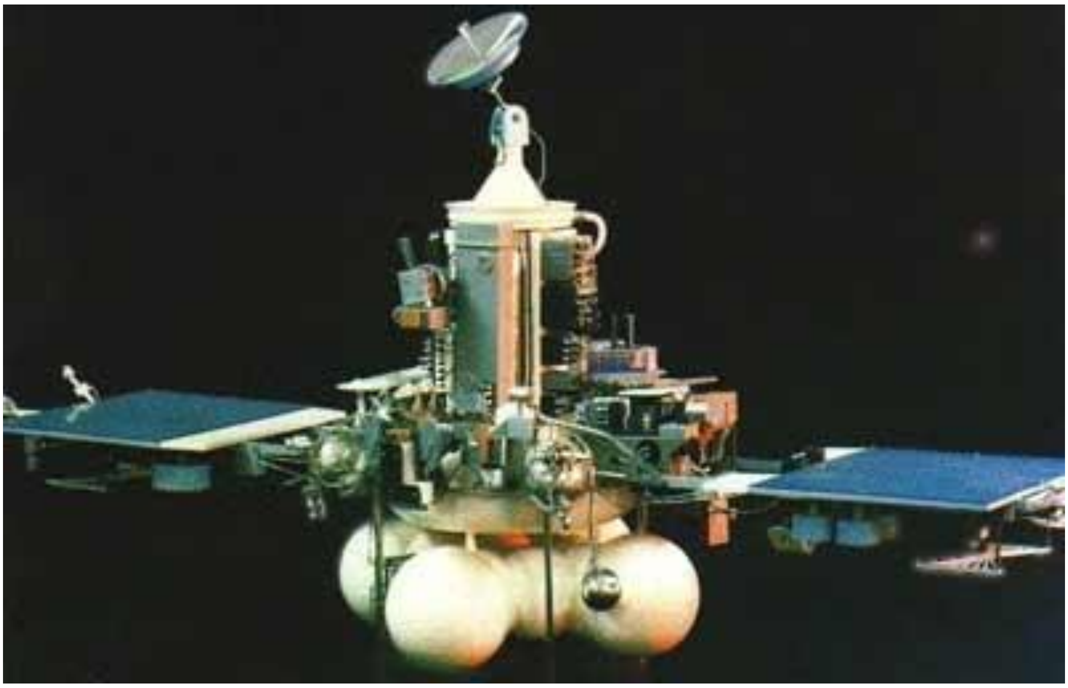

Figure 8: Phobos 1

4. Mars Odyssey

The Mars Odyssey mission is still operating since the year of 2001 when it arrived in orbit on Mars. This chapter on Martian exploration expanded our understanding of the planet and laid the potential cornerstone for a possible human mission. Missions' main objectives are mainly focused on the investigation of geology and mineralogy (Dooling, 2001). According to NASA the name of the mission was selected as a form of contribution to Arthur C. Clarke who is the creator of a science fiction book and co-creator of the film, which bears the same name. "The 2001 Mars Odyssey was launched from Cape Canaveral, Florida, on April 7, 2001, and was named after the science fiction film 2001: A Space Odyssey (1968)." (NASA, 2004)

The Mars Odyssey is an orbiter designed for serving as a communication relay between rovers and Earth's control centre as same as an exploration of the surface. The spacecraft's carrier vehicle was a Delta II rocket. Part of the main objectives is a study of the elemental composition of the surface, determination of the abundance of hydrogen in the subsurface and mineralogy of the surface. Also, the Study of geological processes and climate and the search for the presence of water or other resources that could support future human exploration missions is part of the mission program. Spacecraft gathered elevation data and took approximately 1.2 million images of the surface. These data were used for the creation of a high-resolution map and study of volcanos and craters. The existence of hydrogen in the subsurface, which could suggest the presence of water, was detected and confirmed. This existence was further supported by detecting the water ice in polar regions, which indicates evidence of the watery past of the planet. A weak global magnetic field has been detected with anomalies that make the planets' atmospheres more vulnerable to the solar wind, as well as radiation levels (Dooling, 2001).

The spacecraft carried THEMIS, GRS, MOCC, NS, HEND, AND MARIE scientific instruments on board. The whole system was powered by an array of gallium arsenide solar cells on seven square meter panel. The generated power was stored in a 16-amp hour nickel-hydrogen battery. For communication are used Ultra high frequency (UHF) radio system, which is used for communication with rovers on the surface and a radio system operating in the X-band microwave frequency range (Earth-Spacecraft communication). Sun sensor, Starfield camera and gyroscope devices are the three main systems used for the navigation and control of the spacecraft (Wade, 2019).

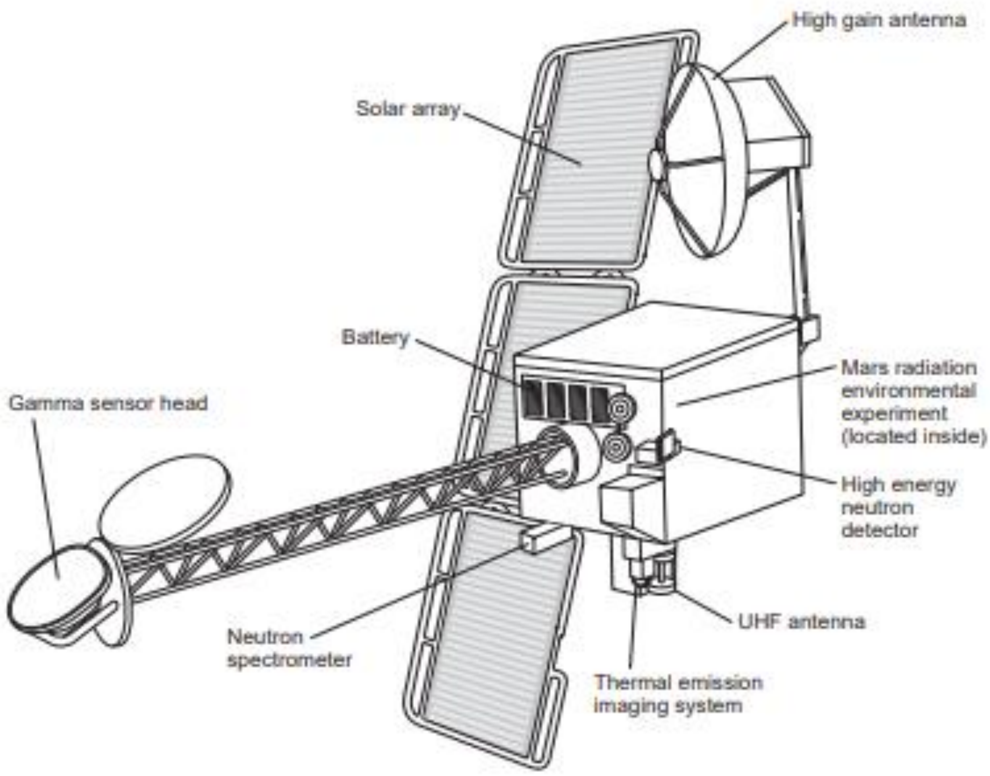

Figure 9: Mars Odyssey

Thermal Emission Imaging System (THEMIS)

THEMIS uses infrared and visible light and its reflections from the surface in order to investigate the planet's geology and mineralogy. Gained data were used for the creation of the geological map, which describes the locations of different minerals and materials from which is land formed. The 11.2 kg device is located on the main body of the spacecraft and has a power of 14 Watts. (NASA, n.d.-a)

Gamma Ray Spectrometer (GRS)

GRS is a solid-state detector used for identifying changes in space gamma rays, which are reflected by the Martian surface in order to discover the amount and types of chemical elements. The source of these cosmic gamma rays in our solar system is the Sun. The energy level of the gamma-ray particle changes as it hits the matter on the surface of the planet. A reflected gamma ray then hits the detector, it generates electrical charges, which are then measured and analysed. The amount of electrical charges detected indicates the element composition of the surface. It is consisted of a Gamma sensor, a Neutron spectrometer and High-Energy Neutron Detector and together weighs 30.5 kg **(NASA, n.d.-b)**.

Neutron Spectrometer (NS)

This scientific device measures the amount of hydrogen located in the subsurface of the planet. It can detect the presence of water or materials which contains water molecule as part of their crystal structure. It is part of the Gamma Ray Spectrometer (NASA, n.d.-b).

High-Energy Neutron Detector (HEND)

It is also part of GRS and it is designed for the measurement of high-energy neutrons emitted from the surface of The Red Planet. Device measures emitted neutrons, which are released from the atoms of elements on the surface as they collide with gamma rays. The gathered data are used for the determination of the composition of the Martian subsurface (Mitrofanov, 2023).

Mars Radiation Environment Experiment (MARIE)

This instrument can detect the radiation levels on the surface. The flux and Intensity of charged particles (Neutrons, protons, heavy ions) are measured by the solid-state detector. The particles come through the detector and generate an electric charge, which is analysed and used for the determination of the type and value of radiation (NASA, n.d.-c).

5. Rovers on Mars

5.1.Pathfinder

The Pathfinder mission, launched in 1996 under the Discovery program, was considered Nasa's low-cost and high-risk planetary mission with the ground-breaking aim of exploring Mars’s surface by lander and Rover. The spacecraft was launched on a Delta II rocket vehicle from Cape Canaveral, Florida. As it is mentioned the mission consisted of the vehicles, an immobile lander Pathfinder and a small mobile rover called Sojourner. Both vehicles gathered data on the atmosphere, geology, soil composition and climate. Coordinates 19.33°N and 33.552°W in the Ares Vallis Basin were chosen for the landing site (Williams D. , 2022d).

A new method of multi-staged landing sequence was used for a safe touchdown of both vehicles on Mars’s surface. This method consisted of 5 stages: Entry, Descent, Airbag landing, Petal deployment and Rover deployment (NASA, 1999). The heat shield protected the spacecraft from heat which was generated by atmosphere friction as the Spacecraft entered the Red planet’s atmosphere at high velocity. A huge amount of thermal energy is created while descending to the planet’s surface and the stability and orientation of the spacecraft must be maintained. “At the point of peak heating the heatshield absorbs more than 100 megawatts of thermal energy.” (NASA, 1997a)

The 12.5m wide Parachute was deployed at supersonic speed at an approximate altitude of 7 kilometres above the surface, while the heatshield was dropped off. The spacecraft is split into the backshell and lander part, which hung to the upper part of the spacecraft The spacecraft's speed was reduced to 60 m/s by the parachutes, and at an altitude of 1.5 kilometres, the airbag system was inflated to cushion the impact on the planet's surface. This system allowed the lander to bounce and roll over the surface, thus ensuring a safer landing. The solid rocket motor fired 80-100 metres above the surface to ensure the complete stop of the spacecraft at an approximated altitude of 10 metres. Then the lander part with inflated airbags is separated from the spacecraft while the backshell with mounted rockets flew away to a nearby place to avoid possible collision with the lander part. The petals were deployed, and the airbags deflated as the lander safely settled. (Williams D. , 2004). The X-band radio transmitter turned itself off for ensuring sufficient battery power for other devices and for the safer cooldown of the whole system. The whole Landing sequence is shown in Figure 10. The Sojourner rover was deployed a day after the landing and began its first operation on another planet.

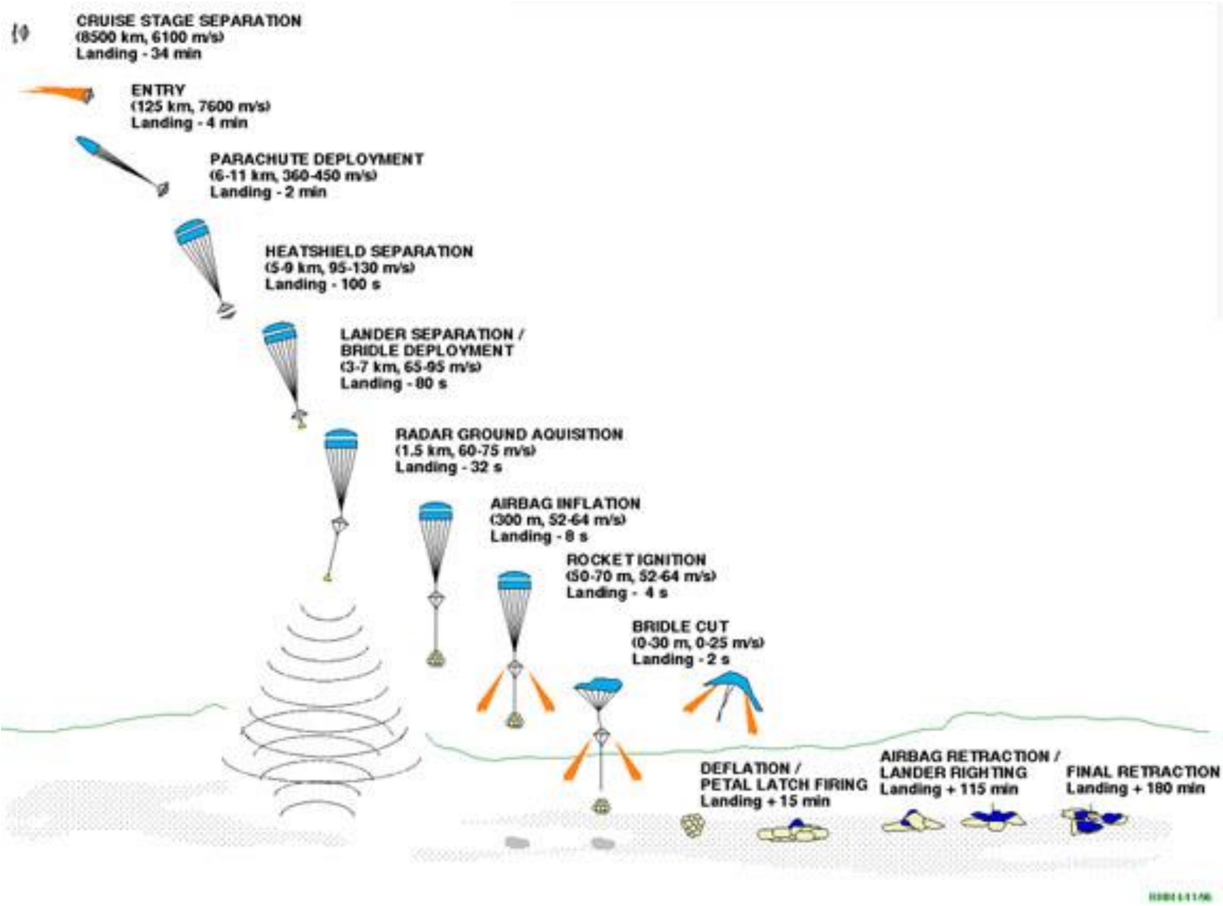

Figure 10: Landing Sequence of Pathfinder vehicle

The Pyramid-shaped pathfinder lander, which can be seen in Figure 11 was equipped with 1200-watt-hour solar panels, attached on the three opened sides, and was used for recharging a silver-zinc battery. IBM RAD6000 computer with 128 MB of RAM controlled the lander and could perform up to 20 million instructions per second. Low-Gain and High-Gain antennae were used for communication between Lander-Sojourner and Lander-Earth control. Among other scientific instruments were IMP, APXS, and ASI/MET. Rover was powered by a 0.25 square solar panel and lithium-chloride batteries that could not be recharged. The maximum speed was one centimetre per second. The Sojourner rover and its equipment weighed approximately 15.6 kg. (NASA, 1997a)

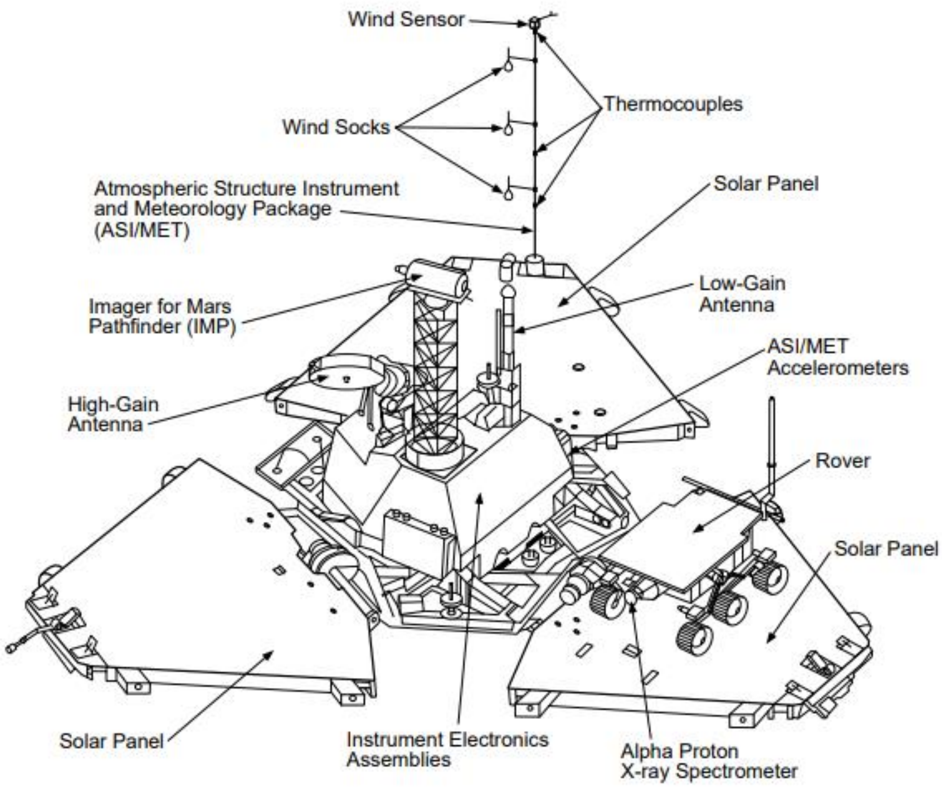

Figure 11: Pathfinder Lander

Imager For Mars Pathfinder (IMP)

IMP was a small moveable stereo imaging system mounted on a 1.0-meter-high mast located on the top of Lander. The system could take colourful panoramic images as it was able to rotate on its axis and change the angle of view, by the movement provided by stepper motors located in the "Head". The charge-coupled device (CCD) has a front-illuminated frame array with 23-micrometre square pixels capable of an image resolution of 512x512 pixels. A colour filter wheel with thirteen different geological filters, including red, blue, and green, allows the use of the colour composition method, resulting in the creation of a colour image. (NASA, 1997b)

Alpha Proton X-Ray Spectrometer (APXS)

This scientific device was part of the rover Sojourner and was used for the determination of the elemental chemistry of the surface materials. It measured the X-rays emitted from the soil as this device blasted it by the alpha particles and protons. This technique was used for the identification of the abundance of elements. This device was mounted in front of the rover on a rotatable deployment mechanism (NASA, 1997b).

Atmospheric Structure Instrument/Meteorology Package (ASI/MET)

Designed for the study of the atmospheric structure of Mars and meteorological observations. Accelerometer, temperature, pressure, and wind sensor are included in this package of instruments. Windsocks, which are located at three different heights, are designed to spin in response to the wind, and thus determine the speed, direction and strength of the blown wind. Sensors measured atmospheric density, pressure and temperature, while the whole spacecraft was descending to the surface. Travis's magnetic reluctance diaphragm sensor was used for pressure measurement. This instrument device is shown in Figure 12. (NASA, 1997b)

Figure 12: ASI/MET instrument package

The Pathfinder managed to send over 2.3 billion bits of data back to Earth, which included 17,050 images from the lander and rover. The Sojourner examined the composition of the soil and surrounding rocks of the lander and was the first mobile rover on the surface of Mars. The rover travelled about 100 meters during its mission (Crumpler, 2021, pp. 123-130). The existence of Ancient Water was confirmed by APXS, which analysed rocks and soil, which contained minerals specific for watery areas. Climate and weather behaviour was observed. Analyse of surrounding Martian soil containing iron, sulphur, and magnesium. The entire mission cost about $265 million and most of the original mission points were met. Both probes were able to exceed their planned lifetime. (NASA, 1999).

5.2.Mars Exploration Rover Program

Mars Exploration Rover (MER) is a mission consisting of the Rovers named Spirit and Opportunity. These fully moveable twin rovers were sent on their journey to Mars in the year of 2003 from Cape Canaveral, Florida. Delta II rockets were used as carrier vehicles for both. The main goal of this was a further study of climate, geology, and search for potentially habitable places and possible life forms on the surface. Both probes exceeded their planned lifetime and found ground-breaking discoveries. MER used a similar landing system as the Pathfinder mission but was more complex. This system has consisted of Airbags, Retrorockets, and parachute.

Six-wheeled Spirit and Opportunity weighed approximately 185 kilograms each. The main box-shaped rover body was made of composite materials and aluminium to ensure the lowest weight possible. Their six-wheeled design, with motors in each wheel, ensured good moveability and a safe speed of 3.75 centimetres per second. Front and Rear wheels were steerable, and each wheel had its own suspension system for better stability of the whole rover. Four solar panels were used to power two lithium-ion batteries, which served as the main energy storage and could easily meet the 100 watts of power requirement. Solar panels were located on the top of the rover and generated up to 140 Watts of power. Rovers were controlled by a computer with 128MB of RAM. Low gain Omni-directional and High gain dish antenna provided communication between Rover and Earth. The rover's equipment also included an extendable robotic arm, with various scientific tools like rock abrasion tool (RAT), APXS and camera for capturing images in detail. APXS was used for the determination of elements that were contained in soil and rocks for evidence that could lead to the discovery of possible water activity on Mars. The RAT was a system in a form of a grinder capable of drilling through hard volcanic rock, to expose to materials below the surface crust to do further searches with other scientific equipment. Pair of high-resolution Panoramic Cameras (Pancam) provided 360° colourful pictures. Mössbauer Spectrometer (MS) was used to identify early Martian environmental iron-bearing minerals and one measurement could take up to 12 hours. Miniature Thermal Emission Spectrometer (Mini-TES) determined the mineralogy of rocks and stones and required power of 5.6 Watts when operating. The Microscopic Imager with a high-resolution camera provided close-up views of the nearby rocks and soil. The image size was 1024x1024 pixels (NASA, n.d.-c). Both rovers were equipped with insulated Thermal protection to withstand the harsh climate, dust storms and high radiation levels. (Williams D. , 2022e)

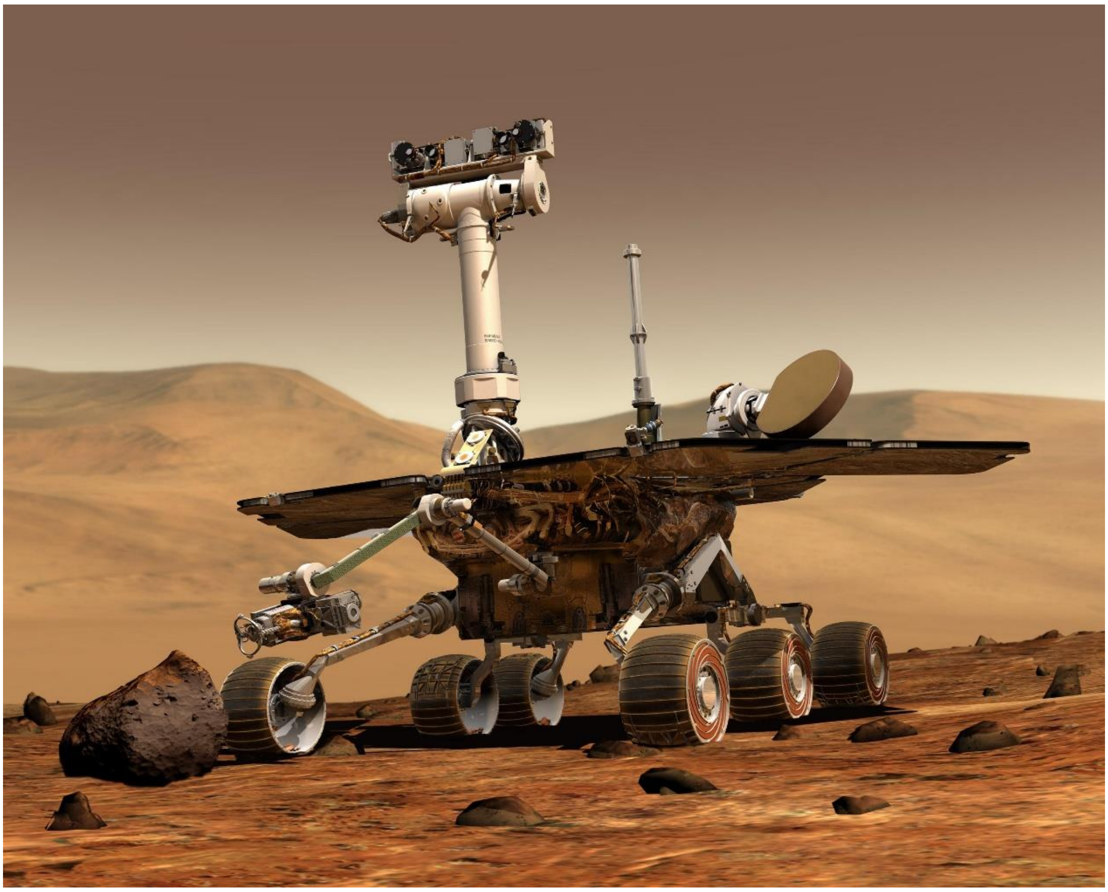

Figure 13: Spirit

5.2.1. Spirit

Spirit landed in January 2004 in Gusev Crater, which may have once been an ancient lake bed. There was clear evidence of a prehistoric system of water channels flowing into the crater (NASA, 2003). After its landing spirit deflates its airbag landing system, deployed its solar panels, and began transmission back to the Earth control. Between the first bits send were images of the surrounding environment. The communication between Earth and Rover was accomplished by an orbiter from the Mars Odyssey program. Just a few days after the landing, a problem in the flash memory occurred and communication with the rover was lost. Spirit was saved by a quick patch and the whole program could continue. Other issues during the mission have occurred like wheel motor failure, dust on solar panels, and enormous dust storms (Williams D. , 2022e).

Spirit successfully surpassed its 90-sols (Martian day) planned mission and was extended multiple times. Spirit had travelled 7.73 km and survived on the surface for approximately 6 years and 2 months when it suddenly became stuck in soft soil. There have been attempts to get the spirit back, but since 2010 communication has not been established and Earth-control declared the mission as completed (Siddiqi, 2018, pp. 222-225).

During the mission, Spirit found clear evidence of past water processes by finding sulphate-rich soils. Measured high concentrations of silica in rocks indicated possible places that could have had suitable conditions for ancient microbial life in the past. The mission found rocks rich in magnesium and iron carbonates that point to a period when Mars may have been a hospitable place for life. Spirit did several climate and weather measurements, including humidity and temperature and found patterns in the form of seasonal changes in weather. APXS and MS analysed the soil and provided information on its chemical and mineral composition to better understand the formation of rocks on the planet (Siddiqi, 2018, pp. 222-225)

5.2.2. Opportunity

The opportunity second twin rover landed in January 2004 in the Meridiani Planum region, which is considered as an area of exposed rock outcrops and vast mineral deposits. Lander´s mission duration was also planned for 90 sols but managed to operate for over 5,498 Sols (almost fifteen years) and travel 45.16 kilometres. By this milestone, the Opportunity rover surpassed its planned lifetime 60 times and became the longest-lasting and most successful mission on Mars. The data collected by Opportunity Rover has greatly expanded our knowledge of Mars and shed light on the planet's geology, climate, and previous habitability (Siddiqi, 2018, pp. 225-227).

Scientifical equipment was the same as for the Spirit rover except for the Mini-Thermal Emission Spectrometer (Mini-TES), which was used for the mineral composition of soil as it was described in the previous chapter. Besides this, rovers were identical.

Rover confirmed and found evidence that liquid water was once present on the Martian surface sometimes in the past. Rock formations with layers and stones which had been shaped by the water flow were discovered, confirming the theory of the past presence of water. Opportunity's study of Eagle and Endurance craters revealed evidence for past inter-dune playa lakes that evaporated to form sulphate-rich sands. The sands were reworked by water and wind, solidified into rock, and soaked by groundwater." (NASA, 2004) Opportunity managed to monitor and image Martian dust devils. Sampled rocks had traces of minerals that indicate the Vulcanic past and processes that helped the shaping of the surface. Also, data on dust and atmospheric clouds and their effect on solar panels have been collected. (NASA, n.d.-d).

A dust storm on Mars in 2018 reduced the battery power as they cannot be recharged because of settled dust on solar panels. The battery power level must been reduced to a such low level that the rover simply ran out of energy and died. Earth control done several attempts to bring the rover back to life and restore communications, but were unsuccessful and on February 13, 2019, the mission was proclaimed as completed (NASA, 2019).

5.3.Curiosity

Curiosity Is a rover launched under NASA´S Mars Science Laboratory (MSL) mission. The name of this rover was selected by a twelve-year-old student named Clara Ma, who won the Mars Science Laboratory naming contest (NASA, 2009). The Curiosity rover is bigger and heavier than its predecessors Opportunity and Spirit and matches the size of a car. Curiosity is still operational and roams the surface of Mars for more than 3786 sols (NASA, 2023).

Quad 51 of Aeolis Palus was selected as the landing point. On August 5, 2012, Curiosity landed fully autonomously on the Martian surface by using the newly developed technology. The landing of Curiosity was nicknamed the „Seven Minutes of Terror", because the rover had to face many hazards alone in the landing sequence without possible and immediate control from Earth. The "sky crane" landing system provided a safer surface touchdown at the final stage of the landing sequence. The rover was lowered from the lander to the ground by this landing system and then the lander part then flew away to a safe distance to avoid a possible collision with the rover. (NASA, 2017).

The main task of curiosity is to detect microbes, which could shed light on the planet's habitability for future human missions. Curiosity shares objectives with previous rovers like the search for evidence of the presence of water on the planet, a study of geology and climate observation. (Siddiqi, 2018, pp. 280-286)

Curiosity is powered by Radioisotope thermoelectric generator (RTG) running on plutonium-238. The whole is controlled by two computers (RCE), which are protected and shielded from radiation. The Computers are running on the VxWorks operating system and have RAD750 CPU. Communication with Earth is managed directly or via relay satellites on Mars orbit. Direct Rover-Earth communication has speeds up to 32 kbit/s and by the use of satellites, the speed can range from 256 kbit/s to 2000 kbit/s. Curiosity has many scientific instruments on board like Mastcam, APXS, MAHLI, MARDI, ChemCam, Chemin, SAM and radiation detectors RAD and DAN (Siddiqi, 2018, pp. 280-286).

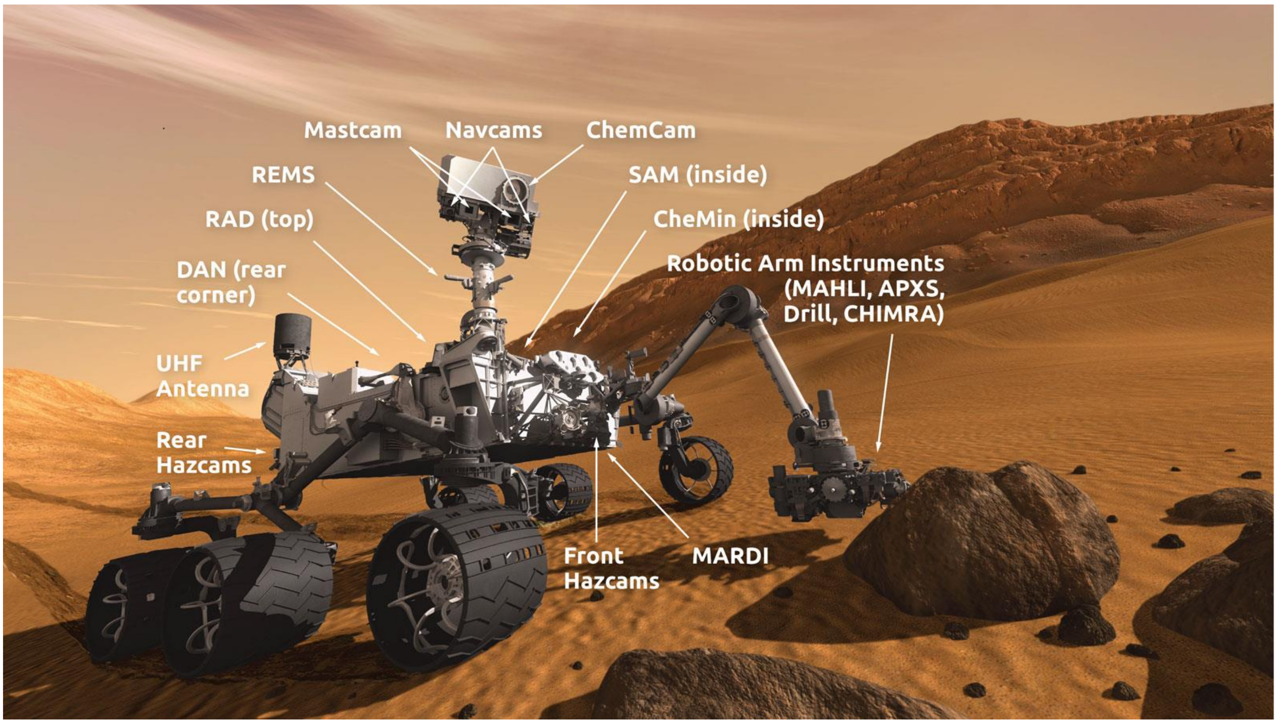

Figure 14: Digital visualization of Curiosity´s instruments

The APXS system was described in Chapter 5.1 of Pathfinder, so its working principle and purpose are no longer stated here

Mastcam

Mastcam is composed of two high-resolution colour cameras that can capture video and panorama. The image size is approximately 1600x1200 pixels and the high-resolution video has a frame rate of 10 frames per second. The captured images are then saved in an 8-gigabyte memory that can store up to more than 5,500 images. Cameras are mounted on the mast, which extends from the rover's main body and can reach a height of 2.0 meters. The cameras themselves are only 25 centimetres apart and could be imagined as the eyes of the rover. This device is also used for the navigation of the Rover throughout the harsh Martian terrain (NASA, n.d.-e).

Mars Hand Lens Imager (MAHLI)

MAHLI is a “camera” with a macro lens, for microscopic imaging. The image size is up to 1600x1200 pixels and has a resolution of 13.9 micrometres per pixel. White and ultraviolet light sources ensure MAHLI working conditions even in low light conditions or at night. This camera is able to capture detailed views of the drill holes to reveal the textures and structure of the rocks. These images can help to understand the geologic history of Mars. Images are stored on a dedicated 8-gigabyte flash memory disk with a 128-megabyte SDRAM (NASA, n.d.-f).

Mars Descent Imager (MARDI)

As MARDI is located on the bottom side of The Curiosity, its main task was capturing images during the descent. It can provide HD colour video with a framerate of 4 frames per second. Images taken during the descent helped scientists to select a proper route for the Rover, by revealing cliffs and boulders that could jeopardize the mission. Images are stored on the 8 Gigabyte flash memory (NASA, n.d.-g).

Chemistry and Camera (ChemCam)

ChemCam is used for the determination and identification of the mineral and chemical composition of the soil. The laser, camera, and spectrograph, located in the main body of the rover, are the main parts of this scientific instrument. The laser fires a beam of light to clear away dust and breaks the surface of a sample. This sample emits light, and its wavelengths and intensity are analysed to identify a quantity of elements (NASA, n.d.-h).

Chemical and Mineralogy (CheMin)

Chemin investigates the chemical composition of powdered rock in cooperation with ChemCam and MAHLI. It is located inside the main body of the rover, and it could be considered as a laboratory on board in a size of a small laptop. The Chemin Analysis of the sample can take up to 10 hours. These analysed minerals can provide information about the existence of olivine and pyroxene, which are formed when lava solidifies. Acquired data are also used for the understanding of how rocks and soil were formed on the surface of Mars. The analysis is performed by a beam of X-rays, which blasts the powdered sample are then interacts with the material. Thus, the sample re-emitted at an energy level which is characteristic of a particular atom (NASA, n.d.-i).

Sample Analysis at Mars (SAM)

Designed to analyse Martian samples chemically and isotopically in-depth. Gas chromatograph, mass spectrometer, and a tuneable laser spectrometer, each with specialized capabilities. It is used to analyse the composition of samples including gases and organic molecules. The chromatograph separates gases based on their chemical properties from a sample. The mass spectrometer measures the masses of ions produced by the sample, allowing the types and abundances of different molecules in the sample to be identified. The tunable laser spectrometer determines the isotopic composition of gases in the Martian atmosphere (NASA, n.d.-j).

Radiation Assessment Detector (RAD)

RAD is in the body of the rover, its upper side facing the sky. It consists of solid-state detectors and thermoluminescent dosimeters, which are used for measuring the intensity, composition, and energy of radiation. These detectors collect data on radiation levels on Mars' surface and how they may vary with time, location, and climatic circumstances (NASA, n.d.-k).

Dynamic Albedo of Neutrons (DAN)

DAN measures the abundance and distribution of hydrogen in the Martian subsurface. It makes use of the neutron detection method to reveal the existence of water ice beneath the Martian surface. This device can provide information about the subsurface makeup and outline the potential habitability of Mars. DAN can detect up to 1/10th of a percent of water in the soil (NASA, n.d.-l).

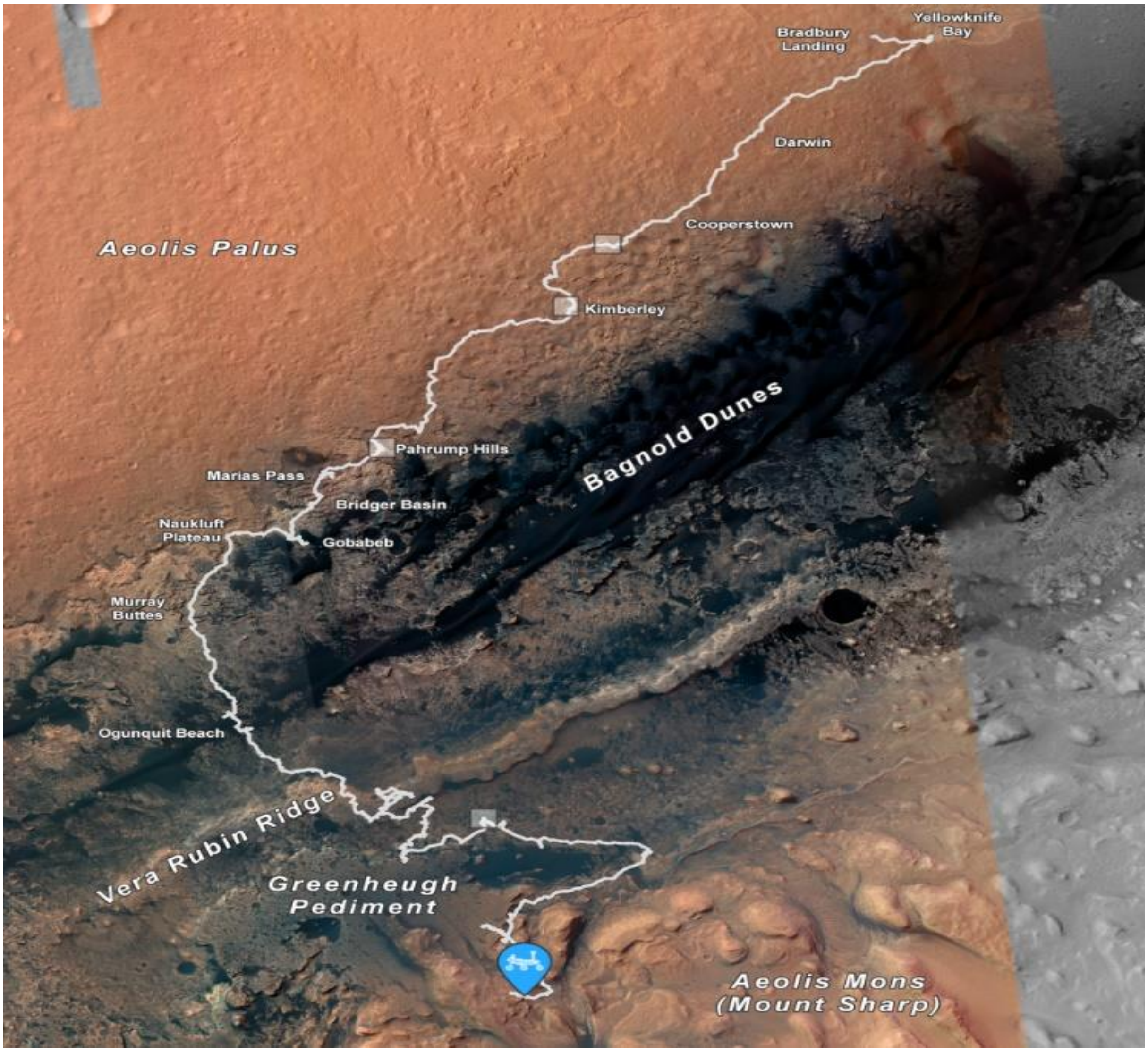

Figure 15: Path of The Curiosity rover

Curiosity is roaming Martian deserts up to now and has achieved remarkable achievements in Mars exploration. It can bring new unbelievable discoveries every day. This mission demonstrated several new technologies, which were firstly used. The landing was accomplished fully autonomously, including several manoeuvres with no real-time control from Earth control.

Curiosity confirmed the past existence of flowing water on Mars and that the soil has suitable composites for support of life. Complex molecules were discovered in Martian rocks and soil as well as methane in the atmosphere. This finding could potentially indicate the presence of some lifeform as methane is only produced by biological or geological processes. In contrast, a high level of radiation was detected and could be considered as a possible threat to future manned missions (NASA, n.d.-m). Figure 15 shows Curiosity's journey to Sol 3483

6. InSight

It is a stationary lander and the first to explore the structure and processes in the deep interior of Mars. Another main objective was a measurement of seismic activity (Marsquakes) by the SEIS (Seismic Experiment for Interior Structure). These data may lead to a better understanding of Mars's core. The mission also included the Heat Flux Probe (HP3), which was designed to measure temperatures from the Martian core that reach the surface. The rotation of Mars was measured by RISE (Rotation and Interior Structure Experiment). Insight landed in Elysium Planitia in November 2018.

The Martian crust, which consists of three sub-layers, was found to be thinner than was previously expected. The core of Mars has a radius of 1.830 kilometres, and it is possibly made of mixed iron elements. Mars's crust is made only of one solid plate and as the planet is cooling down, the plate shrinks. These shrinks create a break in a crust that lead to a Marsquake, during the mission total of 1,319 Marsquakes were detected. The biggest Marsquake detected during the mission had a magnitude of 4.0. Martian dust devils have been detected as well. Unfortunately heat flow experiment had some difficulties, as the soil beneath the lander was tougher than it was previously estimated. The mole did not manage to penetrate the soil to a depth of five meters (Crumpler, 2021, pp. 273-278). Despite this problem, the instrument was still able to collect some data on thermal conductivity. Solar panels, which used to be the main source of electricity, became covered in dust and started to produce less and less energy. This resulted in the lack of power and the lander simply run out of power. On December 20, 2022, Nasa announced the end of the InSight program. The whole program is considered as a success (NASA, 2022).

The Insight lander bid us farewell with a message posted by NASA on its Twitter account: "My power's really low, so this may be the last image I can send. Don't worry about me though: my time here has been both productive and serene. If I can keep talking to my mission team, I will – but I'll be signing off here soon. Thanks for staying with me." (Lock, 2022)

7. Mars 2020

Mission Mars 2020 is the most recent NASA mission on Mars consisting of rover perseverance and small drone helicopter Ingenuity. The mission started on July 30, 2020, when the spacecraft was sent on its journey to Mars. Two-staged Atlas V rocket was selected as a carrier vehicle. The design of Perseverance is inspired by its predecessor the Curiosity rover, but it is bitterly enhanced because of technological advances. The landing sequence is also a bit similar to Curiosity, as it uses certain same features. Mars 2020 studies rocks and sediments on the surface to find the most suitable samples for a future Mars sample return mission. It continues with the search for microbial life (astrobiology) and further study of the climate and geology of the surface of Mars. These acquired data could be used for future manned missions to Mars. The 45-kilometre-wide Jezero Crater, named after small town in Bosnia & Herzegovina, was selected as the landing site (Niebyl, 2021). This site is considered a possible area where traces of past life could be found, as it was a former lake 3.5 billion years ago (NASA, 2021, p. 4). The mission is in the early phase and Perseverance and Ingenuity could potentially reveal some breakthrough discoveries like a fossil of some Martian creature (NASA, 2021, pp. 63-65).

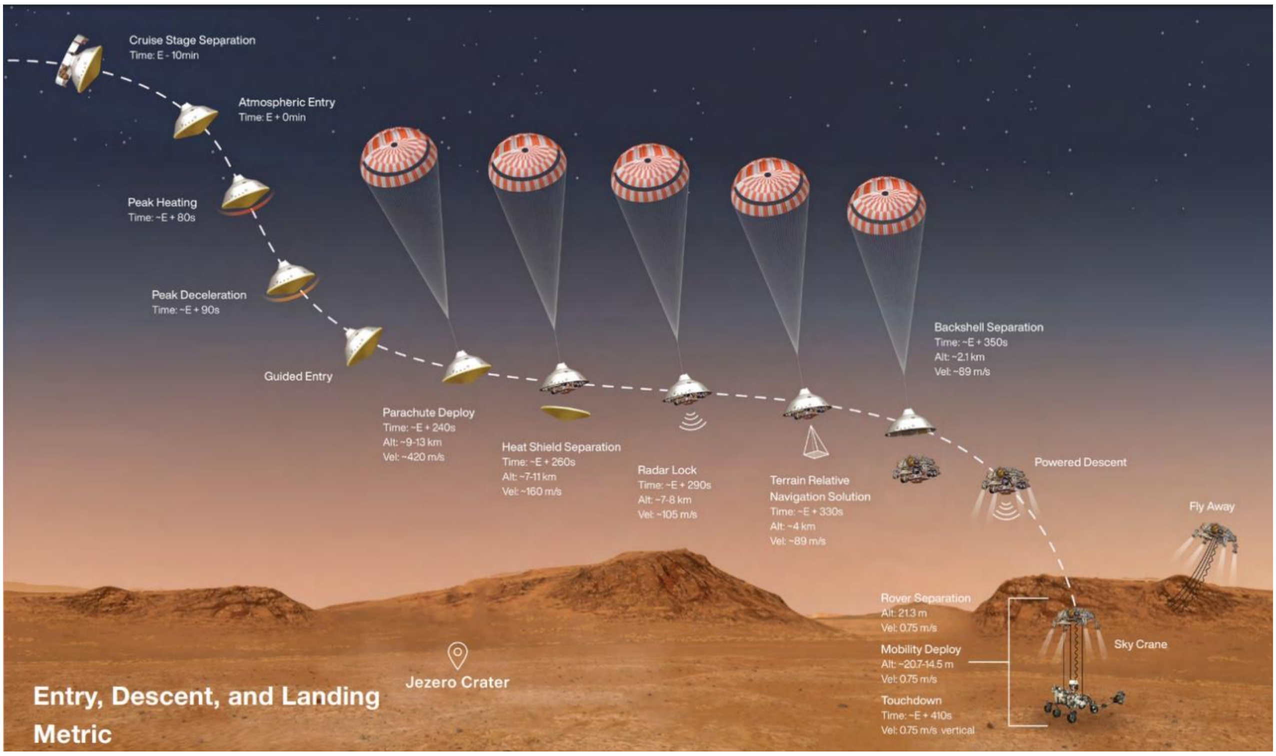

Figure 16: Mars 2020 landing sequence

The landing was done completely autonomously as the communication delay between the spacecraft and Earth control was approximately 11 minutes. During descent, it is difficult to maintain the correct course because the descent module flies through air pockets that have different densities. Small thrusters located on the backshell are used for these course corrections. The 21.5 meters wide parachute was fired at an altitude of 11 kilometres and the heat shield is dropped away. The Terrain-Relative Navigation system is then trying to find a safe area for landing. This system has a programmed map on its computer and tries to navigate the lander to a safe landing location. This is done by comparing the preinstalled map with images of the surface taken by the camera located on the bottom of the lander. When is the safest location found the system corrects a lander's path to this location. At an altitude of 2,100 meters, the backshell separates and the rocket-powered stage fires its eight engines to slow down the descent. When the speed corresponds to 2.7 kilometres per hour and the altitude is 20 meters, the rover is lowered down by a "sky crane". The moment when the rover touches down the "sky crane" is separated and the descent rocket-powered stage flies away to a safe location (NASA, 2021, pp. 16-25).

7.1. The Perseverance

The Perseverance has a weight of around 1,025 kg, including scientific instruments onboard. Each wheel was separately suspended with the motor inside. The 2.1 meters long moveable arm with a rotating turret on its end, houses chemical analysers, a camera, and a drill. This arm is used for drilling into rocks, collecting data for analysis and for detailed camera imaging. Rover is powered by a Multi-mission Radioisotope Thermoelectric Generator (MMRTG) with plutonium-238. Communication on the way to Mars was performed by a low-gain antenna. The communication in the landing sequence was via a UHF antenna mounted on the back shell and mediated by the Mars Atmosphere Volatile EvolutioN spacecraft. A low-gain UHF antenna on board the rover is now used to communicate with Earth. The Perseverance is controlled by two RAD750 computers which serve as the "brain" of the rover. There is another RAD750 computer on board with a special integrated card for analysis of the captured images. This image analysis helps the rover to navigate and choose the most efficient and safest path. The rover has a Sample Caching System that allows samples to be collected and stored in tubes, which will then be picked up and sent on their way to Earth. Mastcam-Z, SuperCam, MEDA, RIMFAX, MOXIE, PIXL and SHERLOC are the main scientific instruments integrated into the Perseverance rover (NASA, 2021, pp. 28-35). The layout of Perseverance equipment and scientific instruments can be seen in Figure 17.

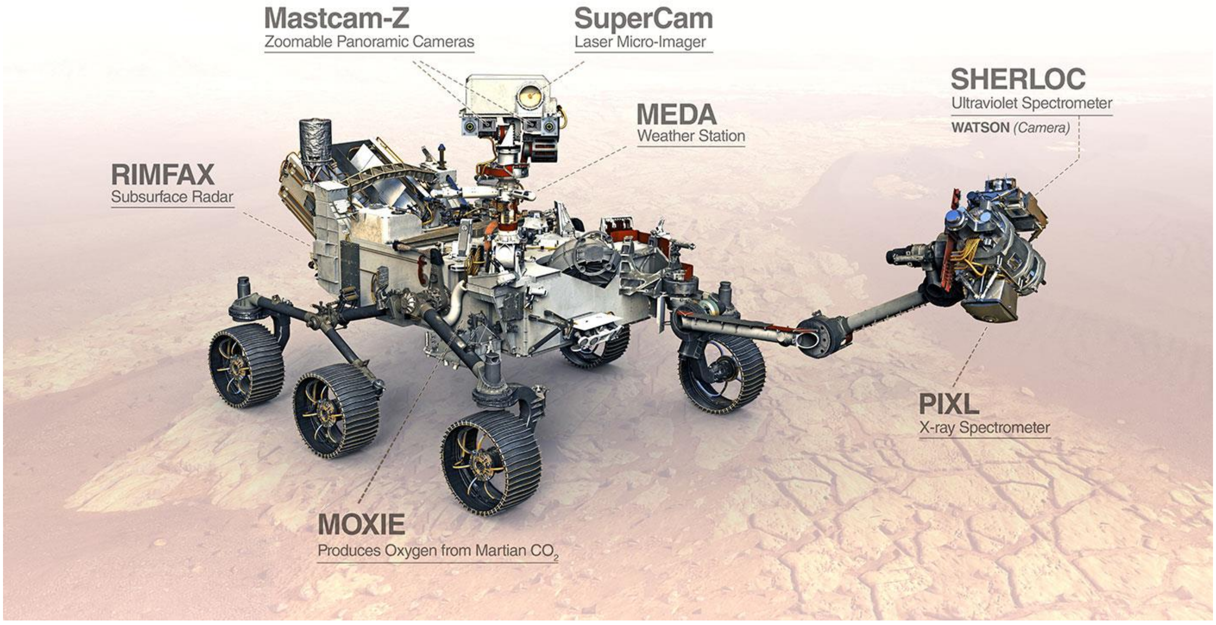

Figure 17: Perseverance instruments

Mastcam-Z

Mastcam-Z is a high-resolution colour camera system capable of 3D, panorama, and video imaging. The camera system has a zoom function, and the image size of a captured image is 1600x1200 pixels maximum. Mastcam-Z can is rotatable in the 360-degree circle as it is mounted on the rover’s mast (NASA, n.d.-n).

SuperCam

SuperCam consists of a camera, laser and spectrometers used to examine rocks and soil where evidence of past Martian life could be found. This device identifies chemical and mineral makeup and is capable of recording sound (NASA, n.d.-o).

Mars Environmental Dynamics Analyzer (MEDA)

MEDA is a scientific tool that measures a wide range of environmental data on Mars' surface. It has sensors that detect temperature, relative humidity, wind speed and direction, pressure, and radiation. Humidity sensors are used for the measurement of water vapour exchange between the soil and the atmosphere. These measurement devices are located on the mast, deck and in the body of the rover (NASA, n.d.-p).

The Radar Imager for Mars' Subsurface Experiment (RIMFAX)

RIMFAX is a ground-penetrating radar device that transmits and receives radar signals to search the ground under the rover. This device can detect water, layers of rock and ice at depths of up to 10 metres. RIMFAX can operate at different frequencies and collect data during the mission, providing a dynamic picture of the Martian subsurface environment (NASA, n.d.-q).

The Mars Oxygen In-Situ Resource Utilization Experiment (MOXIE)

MOXIE is trying to produce oxygen from Mars' thin atmosphere by using solid oxide electrolysis. This solid oxide electrolysis method is used to extract oxygen from carbon dioxide at high temperatures. MOXIE produces up to 10 grams of oxygen per hour. MOXIE has a high potential to act as a major source of oxygen production on the surface of Mars. This oxygen could then extend the astronauts' stay on the surface and help to produce the propellant fuel needed to return to Earth (NASA, n.d.-r).

The Planetary Instrument for X-ray Lithochemistry (PIXL)

By using X-ray fluorescence spectroscopy, PIXL is designed to do fine-scale chemical analyses of the soil and rocks on Mars. PIXL also features a camera that can capture ultra close-up photos of pebbles as small as a grain of salt. It is located on the turrent of the rover´s arm. This instrument has the potential to trace any microbes that might indicate past life on the surface (NASA, n.d.-s)

The Scanning Habitable Environments with Raman & Luminescence for Organics & Chemicals (SHERLOC)

SHERLOC identifies and analyses organic molecules, minerals, and other chemical components on Mars using a combination of Raman spectroscopy, fluorescence spectroscopy, and imaging technologies. This instrument searches day and night for the past and presents organic molecules or biosignatures on the surface. It is mounted on a turrent at the end of the rover's arm. SHERLOC uses ultraviolet laser light for any leftover organic chemicals. The SHERLOC instrument is also involved in testing the spacesuit material, as it carries a small piece to see how the material withstands the Martian environment (NASA, n.d.-t).

7.2. The Ingenuity

The most interesting vehicle apart from the rover is Ingenuity. It was designed as a technological demonstration and proof that flight in a thin atmosphere is possible. Despite the limitations given by the Martian harsh environment and weather, Ingenuity has proven to be a success. Because of the thin density, The Ingenuity must spin much faster than in Earth's atmosphere, gravitation does not represent an issue as is only one-third of Earth's. Ingenuity is also used for scouting terrain in front of Perseverance.

Ingenuity is a small autonomous robotic helicopter with the weight of 1.8 kilograms, which became the first helicopter vehicle to fly on another planet. It has four legs and 1.2-meter length blades made of carbon fibre which have a spinning range of 2,400 to 2,070 rpm. Ingenuity can fly 1,000 meters at maximum with a horizontal speed of 10 m/s. Six li-ion cells, recharged by solar panels on top or by Perseverance´s RTG are used as the main power source. Ingenuity is entirely dependent on its co-partner Perseverance, which serves as a communication relay between Earth control and Ingenuity. This communication is only for data transmission and not for remote control by the pilot from Earth Control. As it is previously mentioned Ingenuity is autonomous and can fly itself. The Perseverance serves as a carrier vehicle for the Ingenuity, which is sideways attached to the underside of the rover and together they travel across the inhospitable landscape of Mars. Because of the distance between Earth and Mars Ingenuity must perform its own decisions, which correspond to parameters which are uploaded before the test flight. The built-in 4208x3120 pixel colour camera is used for in-flight navigation and image capture. Ingenuity has no scientific equipment, except this camera as it is just a prototype to be tested for the first time (NASA, 2021).

The first test flight on the planet took place on April 19, 2021, .by April 13, 2023, Ingenuity had flown 11,546 meters and reached the highest altitude of 18 metres and made a total of 50 flights (NASA, 2023).

8. Humans on Mars

In this chapter, I would like to consider the possibilities of human missions to Mars, list the various problems that the crew of these missions will have to face, and introduce the issues involved in these journeys to the planet.

8.1.Journey to Mars

Sending a spacecraft to Mars is not as easy as one would expect. Earth-Mars distance varies, because of their different orbit around the Sun. The closest distance between our planets is when Mars is the closest point to the sun, which approximately corresponds to 54.6 million kilometres. As it was mentioned, this distance is not always the same, and Mars can be as far as 401 million kilometres from Earth, but the average distance is somewhere around 225 million kilometres (Dobrijevic & Tillman, 2022). Most missions to Mars are conducted in the launch window when are our two planets closest. This time window is not that frequent and only occurs every two years. This journey has an approximate duration of 150 to 300 days using conventional propulsion. This is quite a long time for space travel and a problem can easily occur during this time. If something goes wrong on the way or already on the planet, for example, a shortage of supplies, the astronauts on board are on their own as they have only a limited amount of supplies and equipment that came there with them. Earth control will not be able to send immediate help or supplies as it could take a year or even several years to arrive at the destination (Williams M. , 2021a).

Power production is another problem connected with travelling to Mars as the spacecraft is moving away from the sun. Nowadays, the most used power source are solar panels, which are supplying the batteries on board these spacecraft. As the spacecraft is drifting away from the sun the efficiency of solar panels decreases, resulting in much lower power availability. Manned space travels would have completely different energy requirements than just a probe. Furthermore, to ensure the safety of the astronauts, the spacecraft needs to be heated to a certain temperature to ensure the health of the astronauts and avoid hypothermia, which could cause further health problems (Williams M. , 2021a).

In the case of reducing the flight time to Mars, the use of a suitable rocket propulsion system and propellant would be needed. Chemical rockets are commonly used as carriers, but they are not as effective as the prototypes which are being tested these days. Scientists from NASA are currently researching the possibility usage of two major prototype system, the nuclear electric and the nuclear thermal propulsion. Nuclear electric propulsion has a lower amount of thrust than chemical rockets, but it is more efficient as it consumes less fuel. This system moves spacecraft forward as it pushes the ions through the thruster. The thermal propulsion system uses a phenomenon in which heat causes the liquid to transform into a gas that expands through a nozzle, generating thrust. This system provides very high propellant efficiency and thrust, which is needed for travelling this huge distances between planets. Both systems require further studies and tests as there were not been used yet for any space exploration mission (NASA, 2021).

8.1.1. Hohmann transfer orbit manoeuvre

This manoeuvre is called the Hohmann transfer orbit manoeuvre after Walter Hohmann, who described this idea of travel in 1925. It is being used to transfer a spacecraft from one circular orbit to another circular orbit at a different distance from the central body. Hohmann transfer manoeuvre is often used because it is very efficient and requires the least amount of energy to transfer between Earth and Mars. It consists of two burns of the spacecraft's rocket propeller. The spacecraft's orbit is raised in the first burn to an elliptical transfer orbit that crosses the path of the target planet, and the second burn is done during the apoapsis of the transfer orbit to drop the spacecraft into a circular orbit around the planet. This technique is particularly effective because it makes use of the planet's natural motion in its orbits, which only requires a slight change in speed to move the spacecraft from one orbit to another. This is resulting in low fuel consumption and a reduction of travel time (Hohmann, 1960).

8.2.Mars Base

In this chapter, I would like to briefly mention some of the most important designs of future Martian bases. Mars bases and other habitats are key components of future human space exploration, as they will be used as permanent shelters during future scientific missions. These structures must be efficient, sustainable, safe, and durable to withstand the harsh winds and temperature changes. Not only to withstand the extreme weather, but the larger problem would be the high radiation levels on the surface. There are several plans and studies on what a proper design of such a base should look like. Some studies even focus on a space station-like habitat orbiting the planet, and others on ground bases (Florida Tech, n.d.).

Sufficient energy production, food and water production, the creation of breathable air inside the base, and cost are some of the most important requirements that a future base must meet. The life support systems are very crucial as there will be making the human stay on Mars possible. This system will be responsible for producing fresh water and breathable air inside. Both of these resources can then be used for agriculture, thus providing a food supply for the astronauts. Agriculture on Mars will not be quite the same as on Earth, as the Martian climate with its low levels of sunlight poses unique challenges that can probably be overcome by controlled cultivation of crops within the habitat. The habitat itself can have significant energy requirements, so solar power can be one example of a renewable energy source that offers a reliable and long-term solution, as well as nuclear power, which will certainly meet the energy needs of the entire base. Large solar panels arrays or a nuclear reactor could be deployed on Mars to provide enough power supply for various operations of the base, such as habitation systems, scientific research and communications. The cost of the entire mission, including the transport of materials to build the habitat, plays an important role, as setting up such a base could be very costly and a lack of funding could lead to the demise of the entire project. A future Martian base, whether in the form of a space station or a ground base, will therefore have to be very efficient and safe for the astronauts, but also not that expensive (New Space Economy, 2023; NASA, 2021; Williams M. , 2016).

8.2.1. Mars Base Camp

A Mars Base Camp is a Mars base designed by Lockheed Martin to serve as a space station located in Mars orbit. Mars Base Camp would serve as a command centre where astronauts could live and conduct research while controlling rovers and drones on the Martian surface remotely. The space station is designed for a crew of six astronauts. In order to sustain a crew for extended periods of time, the habitat would be fitted with cutting-edge life support systems, radiation shielding, and communication systems and would utilize the concept of in-situ resource utilization. In-situ resource utilization is a method of obtaining and processing materials from the planet. Advanced life support systems would ensure a continuous supply of breathable air, clean water, and sustainable food production. This space station will consist of several modules that will be sequentially attached to the station. The space station crew quarters will be shielded by radiation shielding in the form of hydrogen tanks, which will protect astronauts inside from radiation and solar particle events. The station will also include workspaces, laboratories, storages, exercise facilities, and other required facilities for the crew's productivity and well-being. The Solar Electric Propulsion system will be used as the main source of thrust to correct the position of the modules. The Mars Base Camp will be powered by four solar arrays with a diameter of twenty meters and a power output of 150 kilowatts on Mars. The solar arrays will store the acquired energy in lithium-ion batteries. The Orion Multi-Purpose Crew vehicle will be used for the transportation of crew as it is a highly reliable deep-space spacecraft and control centre. Four radiators will be attached to the station for thermal control. The space station will be equipped with a reusable descent vehicle MADV, that could transport up to four astronauts to the surface and back in one sol. The MADV will be equipped with six RL-10 equivalent engines, which would run on liquid oxygen and hydrogen (Cichan, Bailey, Norris, Chambers, & Ehrlich, 2016; David, 2017). Figure 18 shows a digital display of the Mars Camp space station orbiting around Mars

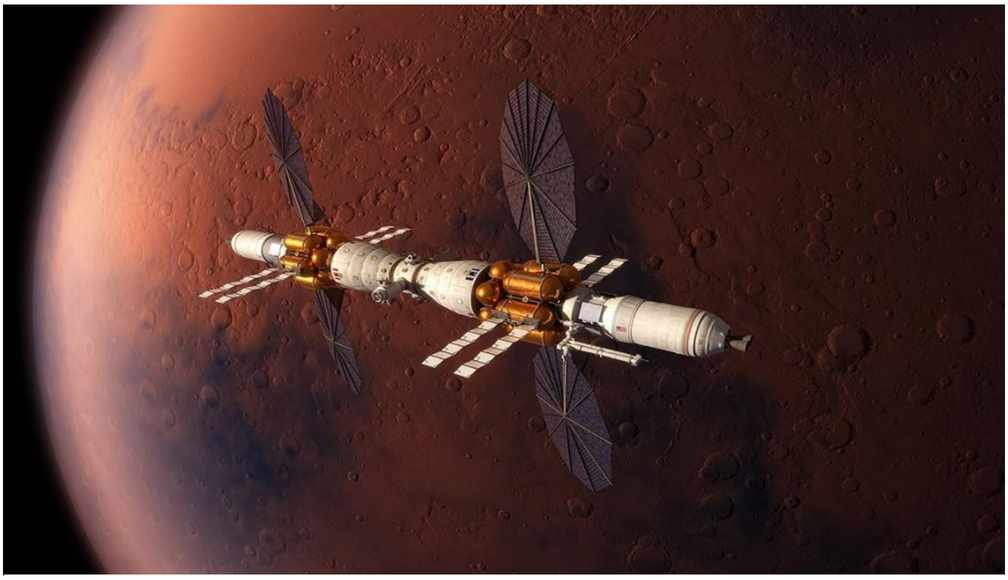

Figure 18: Mars Base Camp space station

8.2.2. Marsha Habitat

Marsha Habitat is composed of an inside module and egg-shaped 3D-printed construction, which shields the inner part. The outer layer of Marsha is designed to be printed from basalt, which is located on Mars and a biopolymer composite. In the first phase of the construction of this habitat, many robots including the 3D printer, will be sent to Mars to acquire and prepare materials for the construction. This printed construction is designed to withstand harsh weather conditions and radiation on the Martian surface. The internal part will consist of four floors, which will include living areas, a dry laboratory, a kitchen, a garden and sanitary facilities (Reilly, 2020).

8.2.3. Mars Ice Home

Mars Ice Home is inflatable habitat shielded from radiation by the water ice, which will be separated from the inner part by a cellular layer of carbon dioxide. The Carbon Dioxide layer will be used as an insulator between the ice and the inner part of the habitat. The use of ice has the advantage of letting in daylight, which will then help astronauts to discern the cycles of the day. This design can reduce the cost of construction as well as the amount of material that would need to be transported to Mars, as ice could easily be made and found on the surface. This shelter will include laboratories, crew quarters, a library, storage, a greenhouse, and a sanitary facility (Clouds Architecture Office, 2016; NASA, 2017).

8.2.4. Eckersley O'Callaghan and HASSELL architect's habitat

This design consists of a 3D-printed outer shell and an inner part with inflatable habitable modules. The Outer part will be a shield for protecting its inside from radiation, weather condition and meteorite strikes. The Regolith, which is located on Mars would be used as a main material. In the first phase of the construction the robots with various functions, including scouting, logistics, excavation, and 3D printing, would prepare the site and build the shell. After the construction of the protective shell. Then the astronauts arrive to assemble the inner part of the habitat (Patil, 2021).

8.2.5. Mars Base Alpha

Mars base alpha is a theoretical concept of future human settlement on Mars created by SpaceX. The four main locations that have been assessed as suitable for this base are Erebus Montes, Phlegra Montes and Arcadia Planitia. The creation of this settlement is closely related to the Starship vehicle, which would serve as a transportation vehicle to the planet and in the first phase of this settlement as the temporal habitat for the first astronauts. These first astronauts will build the landing pads and the necessary infrastructure for further missions. The astronauts will rotate regularly in 26-month cycles when the distance between Mars and Earth is smallest. This project is a have the ambition to create a self-sustaining colony in the form of a small city. This city should be fully self-sustainable in later phases and could lead to the colonisation of the planet, according to their plan (HumanMars.net, n.d.).

8.2.6. The Habitat Demonstration Unit Project Pressurized Excursion

This habitat will consist of a cylindrical-shaped main hub, which will be connected to a hygiene and airlock module. The other two hatches of the main hub can be used for connection of another hub or module making the whole habitat more customisable to astronauts' needs. The main hall is made of composite fibreglass infused with resin and attached to cm steel ribs that support the entire structure. This project will incorporate smart technology with subsystems, which will be automated and capable of self-diagnosis, thus reducing the needed maintenance from the crew. This intelligent system will also detect the presence of a crew and only provide the necessary resources when someone is inside, saving electrical energy and air. This unit will get these readings from multiple sensors. The communication system will have Delay Tolerant Networking, which ensures no data loss during disruptions (Lyndon B., 2010). The layout of the whole habitat can be seen in Figure 19, which displays the main habitat configuration.

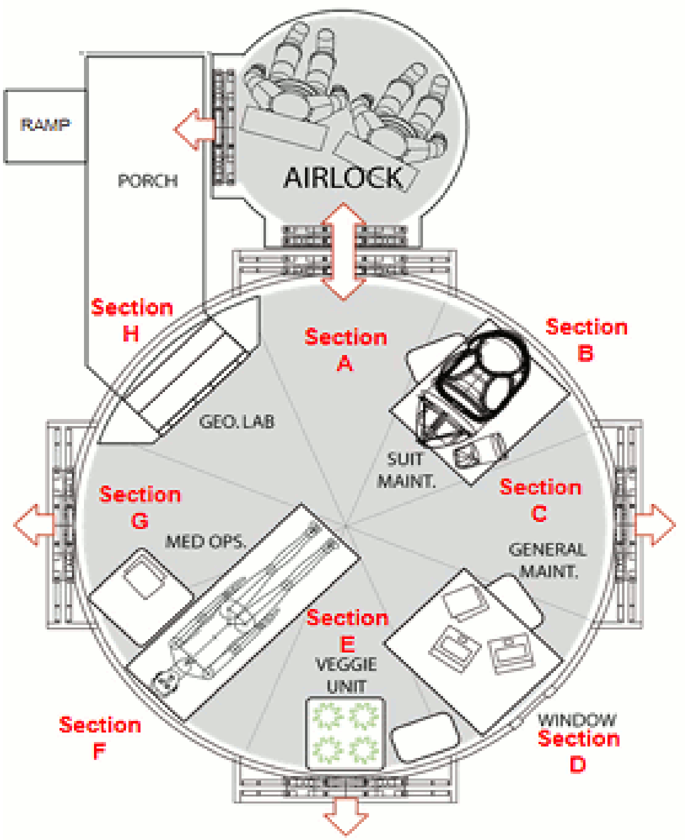

Figure 19: Mars habitat layout

8.3. Health threats

One of the biggest problems astronauts will have to face is radiation. They will be exposed to it both on the way to the planet and also on the surface. These conditions may be very dangerous as long-time exposure to this could result in serious health problems like prolonged cancer and improper brain coordination function and other diseases connected to long exposure to radiation. A study conducted by NASA managed to roughly estimate the levels of radiation, which were related to the exposure of about 1,000 mSv per mission duration. The route to the planet is more dangerous than it can seem, as the approximate amount of radiation was estimated to be 600 mSv and the planned 18-month stay on the planet to 400 mSv (Williams M. , 2021a). These levels can differ from location to location on the surface, but average radiation exposure can be estimated as 2.5 higher than on the international space station. On average human on Earth's surface is exposed to 6.2 mSv annually (Williams M. , 2016).

Another serious health risk is low gravity and isolation from the Earth, which could cause psychological issues. Long-time exposure to low gravity causes bone and muscle density loss, cardiovascular and circulation system problems as well as genetic changes.

Gravity on the Red Planet is 0.375 of Earth's. There is a possibility that the human body could adapt to Mars's low-gravity environment, but there were no detailed studies performed yet. Astronauts returning to Earth would feel nauseous and weak and would have to recover for a long time. There is a theory that a child born on Mars could never visit the Earth, because of the higher gravity density on Earth.

The psychological effects on the crew during the journey to the planet can be dangerous as they affect the proper functioning of the entire mission and high morale and discipline would be required. The crew will potentially face high levels of anxiety and insomnia, as well as depression and feelings of loneliness. They will be isolated from the "rest of the world" on a planet several hundred million kilometres from Earth, which could be very frustrating for astronauts.

Mars s low-temperature environment and deadly frosts result in hypothermia, which endangers the crew. The average temperature on Mars is -63 degrees of Celsius with extreme drops up to -126 degrees Celsius. The crew would have to be very well equipped with space suits capable of withstanding such low temperatures (Dvorsky, 2019).

8.4. SpaceX

SpaceX is a private company, founded in 2002 by Elon Musk. The main goal of this company is to cut the costs of space transportation and travel, with a larger aim to attempt the colonisation of Mars. This company was founded by Elon Mask in 2002. In 2008, the company was awarded a $1 billion contract to supply the International Space Station, which orbits the Earth. Since 2012, SpaceX has been the first private company to make multiple flights with cargo and astronauts to the International Space Station and back to Earth (Eldrifge, 2023).

A major notable achievement of SpaceX is the vision of re-using the rockets and thus cutting the price for space travel. The fleet of SpaceX consists of Falcon 9, Falcon Heavy, the newly developed Starship and Dragon spacecraft. This company is also responsible for the creation of a satellite internet constellation called the Starlink. Starlink consists of thousands of small satellites, which are located in Earth's low orbit, providing a global high-speed internet connection (Grush, 2018).

8.4.1. Falcon 9

Falcon 9 is reusable because the booster can safely land and then be used in another mission. This was first proven in December 2015, when SpaceX managed to land the booster safely (Howell, 2022). Falcon 9 has become the most-flown U.S. launch vehicle in 2022 (SpaceX, 2021, p. 2). The first stage is powered by nine Merlin 1DV+ engines, with a thrust of 854,000 newtons per engine at sea level. The second stage is powered only by one Merlin 1DV+ engine. This engine has the ability to throttle, which allows the adjustment of thrust during the flight and even self-restart ability. These engines run on rocket-grade kerosene (RP-1) and chilled liquid oxygen. The thrust-to-weight ratio is 200:1. Merlin engine is controlled by three computers, which work together to monitor one another and check for any fault. The fuel is pumped into the engine by the LOX/RP-1 turbopump, which spins at 36,000 RPM to produce 7,500 kW. The second stage Merlin engine is designed to be used in a vacuum. It has a larger exhaust section, and the expansion nozzle has a higher ratio of 165:1, which increases efficiency in the vacuum environment (Wevolver, 2023a). Falcon 9 is typically used to launch satellites into Earth orbit, but its successors, Falcon Heavy and Starship, will likely be used to travel to Mars, according to SpaceX.

8.4.2. Falcon Heavy

Falcon Heavy has a similar design as Falcon 9, except it has two additional boosters, each consisting of nine Merlin engines. The Falcon Heavy is currently the most powerful operational rocket, capable of lifting 64 metric tons of material into low Earth orbit. The total of twenty-seven Merlin engines provides a thrust of 5,130,000 lbf at lift-off. The Falcon Heavy consists of two stages. The release of the first stage is done by four pneumatic pushers and a high-pressure helium circuit, which releases the latches, that hold together the vehicle. This is resulting in the separation of boosters, which are then guided back to the landing pad. There is a significant cost reduction because both boosters can be used completely again (SpaceX, 2021, pp. 6-10). The first successful flight demonstration took place in February 2018, when Falcon Heavy flew into Earth orbit with the Tesla Roadster electric car. Both boosters landed successfully, but the main stage had a problem slowing down in the descent phase and hit the ocean at a speed of 480km/h (Howell, 2022).

8.4.3. Starship

The Starship is an ambitious project of a reusable rocket, which is designed to be used as spacecraft for Moon and Mars missions. Two staged Starship vehicles can carry 100+ tons of cargo or one hundred astronauts into the Earth's orbit and beyond. The first stage of this vehicle is the Super Heavy with the purpose of delivering the second stage into the low orbit. It is driven by 33 methalox staged-combustion engines called Raptors and together generates 7,590 tons of thrust. These engines run on chilled liquid methane (CH4) and sub-cooled liquid oxygen (LOX) and have the capability of gimbaling and deep throttling for soft landings. Near its top, the Super Heavy rocket has a set of autonomously operated grid fins. These fins act as air brakes, allowing the rocket to control the centre of pressure and change its pitch or yaw by moving oppositely facing pairs of fins. The rocket can also roll by simultaneously moving the opposing pairs of fins. The booster's current design incorporates six deployable landing legs that help ensure safe landings. The second stage has the primary purpose of transporting the cargo and astronauts. This stage is powered by three sea-level Raptor engines and other three vacuum Raptor engines. Raptor engines are capable of self-starting if it is needed. The stability and control at the re-entry stage of flight are provided by two forward and two rear flaps. The first and second stages are completely made of stainless steel 30X, which withstands atmospheric temperatures at re-entry and low cryogenic temperatures (Wevolver, 2023b).

This newest space vehicle of the SpaceX fleet was first tested in April 2023 after several launch delays. The vehicle was launched from Boca Chica in Texas and four minutes into the flight, the rocket started to spin, which had the purpose of separating the Super Heavy booster from the whole vehicle. The booster did not separate and the whole vehicle blow up in the air. SpaceX does not consider the test flight a failure, but rather a success, as Starship is only a prototype that managed to take off from the launch pad after all (Wattles, 2023; Smith, 2023).

8.4.4. Manned mission to Mars

SpaceX founder Elon Musk revealed his plan to carry out a manned mission to the Red Planet by the end of the 2020s at a presentation at the 2017 International Astronautical Congress. In addition, their vision is to build a self-sufficient city on the surface of Mars that can be visited by anyone, not just scientists. Musk estimated that this city will probably require an investment of $10 trillion. His further aim is to establish a working colony on the surface as early as the 2050s (Brown, 2022).

The Starship would be very likely used for travels to Mars as it is powerful enough and has the possibility of transporting huge payloads. In his plan, several Starships will be sent to the Red Planet in 2029 in the 30-day window, when the planets are closest to each other. As it is previously mentioned this launch window occurs only once every 26 months, so the plan has to be very precise and elaborate, otherwise, the whole mission could end in failure. The Company's main goal is to establish a long-term human settlement on the Red Planet, starting with the transportation of supplies and crew to build the foundation for such a settlement. Starships will probably be refuelled in orbit and launched to Mars in small fleets. SpaceX plans to start building Starships in large numbers and expects to build up to 100 of the vehicles annually. The whole plan is very ambitious, but unlikely, because SpaceX does not yet have the number of Starships required and the funding to build that many Starships for several decades. SpaceX indicates that the long-term survival of our civilization depends on making humanity a multi-planetary species. The program is expected to carry up to one million passengers to Mars by 2050, creating a huge colony. The final estimation involves the construction of 1,000 Starships, which would ensure the supply chain for future Mars colonies. SpaceX has an interesting plan, but in the general opinion, it is difficult to realize such a project that quickly (Brown, 2022; Dvorsky, 2022).

Conclusion

The main task of this bachelor’s thesis was to describe and summarize past and present space missions to Mars and state their main objectives and findings. Furthermore, I described and listed the scientific instruments and technology used during these missions. In addition, this bachelor’s thesis also explores the possibility of human space travel to Mars.

The first chapter focused on the first missions to Mars, which took place in the 1960s and 1970s under the influence of the Cold War rivalry between the United States and the Soviet Union. Although the Soviets made great strides in their exploration of Venus, this was unfortunately not the case with Mars. Almost Soviet Mars programs ended up in failure or did not work as they should have. NASA was a bit more successful with its Mariner and Viking programs, which produced the first breakthrough discoveries. These programs managed to completely map the planet from orbit and the landers managed to take and send the first images from the surface of the Red Planet.

In the next chapter, a description of the Soviet Phobos 1 and Phobos 2 missions was provided, with their purpose to explore Mars’s moons Phobos and Deimos. Although both Phobos probes ended in failure, the Phobos 2 at least managed to provide data on the Sun during its journey.

In 1997, the focus on Mars was reignited with the successful landing of the Pathfinder mission and the rover Sojourner. This mission not only successfully landed on the Martian surface but also conducted scientific experiments and sent back valuable data. This success was followed a few years later by other missions, such as the Spirit and Opportunity rovers. These resilient machines have far surpassed their expected lifespans and have provided compelling evidence of water's presence in Mars's distant past.

Curiosity and Mars 2020, among the numerous missions conducted by NASA, have significantly advanced our understanding of Mars. Curiosity, equipped with cutting-edge technology, has made ground-breaking discoveries, such as evidence of past water activity and the detection of organic molecules, hinting at the potential for ancient microbial life. Similarly, the Mars 2020 mission, with its advanced instruments, aims to further unravel the planet's mysteries, including the search for signs of ancient life and the collection of samples for potential future return to Earth. Notably, the Curiosity rover and the Mars 2020 mission have played pivotal roles in advancing our knowledge about Mars’s past.

In conclusion, the last chapter of this bachelor's thesis explores the intriguing possibility of a crewed mission to Mars, with a focus on the health risks that astronauts would face during their journey and their stay on the planet. In addition, I highlighted how the Hohmann transfer orbit is a crucial key for enabling travelling between Earth and Mars. This chapter also examined the topic of creating a suitable habitat for Mars while taking into account the particular difficulties presented by the planet's environment.

There were many missions accomplished by different companies and government agencies, like NASA and SpaceX. Some probes and rovers have been very successful and have found many breakthrough discoveries during their missions, which have extended our understanding of Mars a little further.

The persistent hope of discovering some form of life on Mars remains strong, with active missions like Mars 2020 diligently exploring the planet and holding the potential to unveil groundbreaking discoveries. Simultaneously, the once-distant dream of sending humans to Mars is becoming a tangible reality as an increasing number of nations and other organizations demonstrate a strong interest in sending humans to the Red Planet.

Rozšířený abstrakt:

Hlavním cílem této bakalářské práce bylo důkladné prozkoumání jak minulých, tak ale i současných misí, které dopomohly našemu lepšímu porozumění planety Mars. Tato práce se snaží detailně analyzovat tyto programy a mise a uvádět jejich jednotlivé úspěchy, technologie a vědecké zařízení, které byly použity během jejich průběhu. Bakalářská práce se dělí do osmi hlavních kapitol, které se zabývají jednotlivými programy spojené s touto planetou.

První kapitola se zabývá šedesátými a sedmdesátými lety minulého století, tudíž by se dalo říct, že se zabývá samotným počátkem vesmírného průzkumu Rudé planety. Tato kapitola se detailně zabývá jak sovětskými, tak i americkými programy, které hrály klíčovou roli v tomto průzkumu. Tyto dvě země byly v těchto letech rivalové, kteří spolu soupeřili, ať už z politického, tak i vědeckého hlediska. Sovětské a americké programy byly silně motivovány snahou překonat se navzájem a dosáhnout významných vědeckých průlomů. Dalo by se říct, že tyto dvě země spolu v podstatě soutěžily o to, kdo dosáhne lepších vědeckých výsledků a přinese cennější informace o této tajemné planetě. Toto soupeření vedlo k pokroku ve vesmírné technologii a výzkumu Marsu.

Sovětský svaz vyslal několik misí, které zahrnovaly jak orbitální sondy, tak i přistávací moduly. Tyto mise měly za cíl získat informace o atmosféře, povrchu a geologii Marsu. Jednou z nejvýznamnějších misí byl program Mars, který zahrnoval mise jako Mars 2, Mars 3, Mars 4, Mars 5 a další. Mise Mars 2, která byla vyslána v roce 1971, zahrnovala přistávací modul a družici, která měla pozorovat Mars z oběžné dráhy. Bohužel, přistávací modul nedosáhl povrchu planety úspěšně, ale i přesto se mu podařilo poskytnout cenné informace o atmosféře a geologii. Další misí byla Mars 3, která úspěšně přistála na povrchu. Tato mise byla úplně první, která přinesla snímky z povrchu Marsu. Sovětský vesmírný program také spustil program Phobos, který byl složen z dvou sond Phobos 1 a 2. Tyto mise byly původně zaměřené na průzkum měsíců Marsu Phobos a Deimos. Obě sondy byly v dlouhodobém měřítku neúspěšné, ale i přesto se jim podařilo pořídit důležité poznatky o našem Slunci při jejich letu k cílové planetě.

Práce se dále zabývá misemi Mariner, které byly vyslány společností NASA. Tento program byl taktéž zahájen v šedesátých letech a zahrnoval několik úspěšných misí. Mariner 4 byl první sondou, která proletěla kolem Marsu a poslala zpět detailní snímky povrchu. Mise Mariner 9, vyslaná v roce 1971, poskytla první globální mapu planety.

V této kapitole je také zahrnut popis a vývoj raket Atlas, které byli používány pro dopravování těchto sond.

Viking 1 a 2 byly sondy složené z orbiteru a přistávacího modulu, kterým se podařilo úspěšně přistát na povrchu Marsu. Tyto mise byly vyslány NASA v roce 1976 a jejich hlavním úkolem bylo hledat stopy možného života na povrchu. Mise Viking byla průlomová v tom, že poskytla první detailní pohled na povrch Marsu. Kamery landeru poslaly zpět velké množství snímků, které umožnily vědcům studovat geologické formace, povrchové rysy a další charakteristiku planety. Viking také získal data o atmosféře Marsu a provedl analýzu půdy.

Čtvrtá kapitola se věnuje misi Mars Odyssey, která byla vypuštěna v roce 2001 a jejím hlavním cílem bylo provést průzkum atmosféry Marsu, hledat zdroje vody a dále mapovat povrch. Mars Odyssey byla vybavena různými vědeckými nástroji, včetně tepelného infračerveného spektrometru, který zkoumal složení povrchu, a neutronového spektrometru, který hledal přítomnost vodního ledu pod povrchem. Tato sonda byla vybavena i dalšími přístroji, které jsou detailně popsány v této kapitole. Mars Odyssey také slouží jako komunikační relé pro další vesmírné družice a sondy, které se nachází na povrchu Marsu.

Pátá kapitola této práce se zabývá rovery, které v dnešní době představují klíčovou součást moderního průzkumu Marsu. Tyto rovery jsou navrženy tak, aby zvládly odolat nehostinným podmínkám Rudé Planety. Rovery jsou pohyblivá vozítka, která umožňují provádění rozsáhlejších průzkumů, vědeckých experimentů a sběr dat z různých oblastí Marsu. První z takových misí byla mise Pathfinder, který se skládal ze stacionárního landeru a malého rouveru nazvaného Sojourner. Pathfinder poté následovaly dva plně mobilní rovery Spirit a Opportunity, které byly součástí mise Mars Exploration Rover (MER). Tyto rovery byly vyslány společností NASA v roce 2003 s cílem pokračování v průzkumu povrchu Marsu. Hlavním cílem tohoto programu bylo hledání stop vody a zkoumání geologie a složení povrchu planety. Původní délka mise rouverů Spirit a Opportunity byla plánována na dobu 90 solů (sol je jeden Marský den), ale oběma roverům se podařilo několikanásobně překonat tento plán a pokračovaly dále v provozu. Spirit pracoval až do roku 2010, kdy se zasekl v písku a oficiálně byl ukončen v roce 2011. Opportunity překonal Spirit o několik let déle a pokračoval v provozu až do roku 2018, kdy roveru došla elektrická energie. Obě vozítka přinesla mnoho cenných informací o povrchu Marsu. Spirit objevil důkazy o dávné přítomnosti tekuté vody na povrchu Marsu. Opportunity se podařilo objevit minerály, které vznikly kvůli přítomnosti vody. Obě mise měly velký úspěch v průzkumu Marsu a poskytly nám mnoho důležitých informací o historii a geologii planety. Curiosity je jeden z dalších rouverů, který je vybaven širokou škálou vědeckých nástrojů, včetně vrtáku, laserového záření pro analýzu chemického složení a kamery pro fotografování okolí. Tento rover provádí rozsáhlý průzkum kráteru Gale, kde se nachází starý říční systém, a objevil důkazy o možné přítomnosti vody a důkazy o možných podmínkách pro život v minulosti této planety. Tato mise stále pokračuje a je možné, že se jí podaří zjistit daleko více informací o této planetě než její předchůdci.

Další kapitola se zabývá programem InSight, který byl vyslaný v roce 2018. Tato mise se skládá ze statického přistávacího modulu vybaveným speciálními nástroji pro zkoumání hlubinné složení povrchu Marsu. Jeho hlavním cílem bylo získat podrobné informace o geologické aktivitě, teplotě, seismické činnosti a jádru Marsu. Tento program byl ukončen v roce 2020, kdy tomuto modulu došla elektrická energie z důvodu zaprášení jeho solárních panelů marským prachem.

Sedmá kapitola se zabývá programem Mars 2020, který je složen z roveru Perseverance a Ingenuity, který se stal první autonomní létající helikoptérou na cizí planetě. Rover je vybaven vědeckými nástroji jako je SuperCam, MEDA, RIMFAX, PIXL, CHERLOC a MOXIE, který zkoumá možnosti výroby kyslíku z atmosférického oxidu uhličitého. Všechny tyto přístroje jsou detailně popsány v této kapitole. Mars 2020 je důležitou misí, která nám snad poskytne nové a cenné informace o Marsu. Díky vylepšeným technologiím a vědeckým nástrojům bude moci rover Perseverance provádět průzkum na větší vzdálenosti a ve větší hloubce než jeho předchůdci. Mise také představuje krok vpřed v našem úsilí o přípravu budoucích misí s lidskou posádkou na Mars a hledání odpovědí na otázky o původu a existenci života na této planetě.

Poslední kapitola této bakalářské práce se zaměřuje na možnosti cest člověka k Marsu, uvádí různé zdravotní a logistické problémy, kterým bude muset posádka během cesty a na planetě čelit. Dále tato kapitola představuje různé návrhy prvních habitatů a obydlí jak na povrchu, tak i na oběžné dráze Marsu. Poté se věnuje společnosti SpaceX a představuje jejich ambiciózní plán kolonizace Marsu. Jsou zde představeny hlavní vesmírná plavidla, která budou zřejmě použita k naplnění jejich vize. V samotném závěru této práce jsou pak shrnuty všechny důležité mise a informace o nich.

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