

Mission overview and key technologies of the first Mars probe of China

YE PeiJian¹, SUN ZeZhou², RAO Wei² & MENG LinZhi^{2*}¹China Academy of Space Technology, Beijing 100094, China
²Institute of Spacecraft System Engineering, Beijing 100094, China

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The first Chinese Mars exploration will fulfill the goals of “orbiting, landing and roving” in one mission. This paper briefly describes the process of international Mars exploration and analyzes the development of Chinese Mars exploration. It focuses on introducing the scientific significance and engineering difficulties of Mars exploration, and provides an overview of the system design of the probe, including the flight profile, the preliminary selection of the landing site, the entry, descent and landing (also known as EDL) process. Four types of key technologies, including telecommunications, autonomous control, the EDL process, and its structure and mechanism, are detailed in this paper. Finally, the paper highlights the expected scientific and engineering results of the mission.

Mars mission, key technologies, China

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1 Introduction

Of all the planets in our solar system, Mars is most similar to Earth. For this reason, generations of people have dreamt of its exploration. Questions, such as the existence of water and life on Mars and the possibility of transforming Mars into a green planet suitable for human habitation, have inspired several exploration missions to Mars. Indeed, Mars exploration represent the pinnacle of interplanetary space exploration and technology, and is the first target in planet exploration for major aerospace countries.

The launch window of Mars reappears approximately every 26 months, and there will be two launch windows before 2020. Considering the plans of other countries, there will be missions for each launch window, and 5 missions altogether for both windows. The first Mars exploration mis-

sion of China is scheduled to launch in 2020 with the goals of “orbiting, landing and roving”. This paper introduces the development process of Mars exploration missions, provides a description of the general design, the mission difficulties and characteristics, as well as the key technologies of the mission, and gives an overview on the expected outcomes.

2 A brief history of Mars exploration

Mars exploration began in the 1960s [1] when the Soviet Union launched the first Mars probe. At present, there have been 43 missions to Mars, in which 20 of them belong to the United States, 19 belong to the Soviet Union/Russia, 1 belongs to Japan, 2 belong to the ESA and 1 belongs to India. Among these, 23 explorations have been completely successful or partially successful, giving a success rate of approximately 52%.

International efforts for Mars exploration can be divided

*Corresponding author (email: 13661078229@163.com)

into two phases with respect to the mission's target. The first, i.e., "technology driven" phase (1960–1988), was characterized by several launch missions with low success rates and a focus on developing the critical technologies necessary for interplanetary exploration. The second, i.e., "science driven" phase (1988–present), is characterized by relatively few launch missions but with significantly improved success rates. In the latter, the in-orbit time is long, and the scientific achievement is rich. The major driving force of the first phase was to develop technologies related to deep space exploration, pursuing longer flight distances and longer exploration time. With improvements in the technical capabilities, the second phase changes from one of technological development to one of acquiring scientific data.

Regarding technological development, Mars flyby, orbiting, landing and roving have already been realized. The more difficult sampling and manned exploration still have technical limitations that must be overcome. The United States has fully mastered the technologies of Mars flyby, orbiting, landing and roving. The Soviet Union/Russia has achieved Mars flyby and orbiting exploration. It has attempted landing on Mars four times, but only one mission (i.e., "Mars-3") has been partially successful in this regard [1]. The ESA has mastered orbiting exploration technology by implementing its "Mars Express" mission. As to Japan, it completed the "Hope" mission with a Mars flyby but did not enter Mars' orbit. Finally, India has mastered orbiting exploration technology by carrying out its "Mangalyaan" mission.

In terms of scientific research, significant achievements have been made in a variety of disciplines, such as orbital motion, determining the parameters of Mars, the radiation environment of Mars under the influence of its magnetic field, the atmosphere, topography characteristics and geological structures of Mars, the surface material (i.e., rock, mineral and chemical element) of Mars, the internal structure of Mars. In 2015, NASA successively announced several important discoveries concerning Mars, including the existence of liquid water in an ancient lake on the Martian surface, liquid water in the underground soil and aurora phenomena [2]. These scientific discoveries enhance our understanding of Mars and provide important data for seeking signs of life on Mars. Moreover, these results will greatly influence future exploration of the solar system and the pursuit of extraterrestrial life.

3 Scientific objectives

International Mars explorations have already made many important discoveries. Results show that there are large craters formed by the impact of small bodies and marks of flood wash. The interior of Mars had sufficient heat, magnetic field and partial plate movement in the past, and it is geologically

active with volcanoes. Further, Mars has a much denser atmosphere and possesses liquid on its surface. The "Curiosity" rover recently discovered minor traces of methane in the Martian atmosphere [3,4]. Chinese scholars found Martian organic carbon in the meteorite "Tissint" and determined its biogenic profile. To date, this is the most powerful evidence for the existence of life on Mars. These discoveries suggest that Mars once had an environment suitable for life.

The scientific goals of the Chinese Mars exploration mission are to explore the characteristics of Martian underground water, soil and rock; study the environment for the existence of life; measure the characteristics of the Martian physical field, atmosphere and meteorology; and study the surface environment and its variation. Moreover, the role of wind, water (ice), volcanoes, impact and structure activities in the formation and reformation of the Martian surface morphology will also be examined to reveal Mars' geological characteristics and its evolutionary history. Focusing on the interaction between geological structure, climate cycle, life and its residence, this mission will also conduct research on the evolution of the planetary system and comparative planetology.

This mission will perform global and general exploration of Mars using in-orbit exploration. By roving exploration, this mission will conduct detailed investigations of key areas with high accuracy and resolution. Specifically, our goals include the following.

- 1) Investigate the characteristics of Mars' morphology and its geological structure.
- 2) Investigate the soil characteristics and water-ice distribution on the Martian surface.
- 3) Investigate the material composition on the Martian surface.
- 4) Investigate the Mars' ionosphere and the characteristics of its surface climate and environment.
- 5) Investigate the physical field and internal structure of Mars. Detect and measure the Martian magnetic field characteristics.

4 Mission overview of the first Mars probe

4.1 System composition of the probe

The probe for the first Mars exploration mission is comprised of an orbiter and a lander/rover, as shown in Figure 1. The orbiter carries the landing/roving probe to complete the flight process of the Earth-Mars transfer and the Mars capture and orbit maneuver. After releasing the landing/roving probe, the orbiter will perform in-orbit scientific exploration. The landing/roving probe is comprised of an entry capsule and a Mars rover. The landing/roving probe will enter the Martian atmosphere at a preset attitude, land safely on the Martian surface after multiple deceleration stages and release the Mars rover for subsequent scientific exploration on the Martian surface.

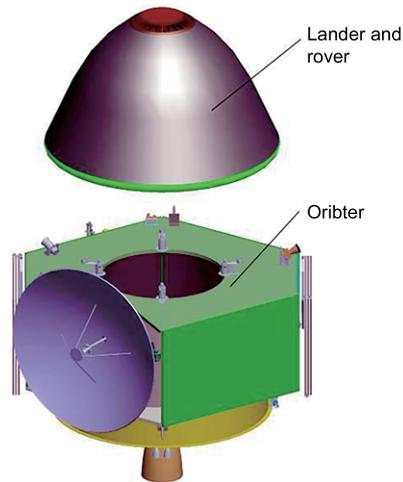


Figure 1 Configuration of the Mars probe.

4.2 Preliminary selection of the landing area

Selecting the landing site is crucial for the design of the mission and affects a variety of aspects such as the orbit design and key parameters of the landing/roving probe. Major considerations in the selection of the landing area include the following.

1) Latitude. This aspect is related to telecommunications, energy consumption and thermal control. The selection must consider the design request of the Mars rover, such as power supply, Earth's direction, surface wind, opacity of the atmosphere.

2) Geographic elevation. To ensure a safe landing, the elevation of the landing area must be sufficiently low to permit sufficient space for the parachute and power deceleration.

3) Topographic slope. These characteristics determine the control capability during the entry, descent and landing

(EDL) process. It mainly affects the radar measurements and the stability of the landing platform.

4) Coverage of dust. This aspect primarily affects the load capacity on the Martian surface and the energy/thermal control of the rover. Areas with little Martian dust are preferred.

5) Distribution of rocks [5,6]. This aspect mainly affects the touchdown safety and mobility of the rover. The ability of the probe to avoid obstacles must be emphasized.

6) Local wind speed. This aspect mainly affects the parachute descent and the thermal control of the Mars rover. To contribute to a safe landing, areas with lower wind speeds are preferred.

7) Visibility requirements during the landing process. The entry and landing process should be scheduled on the side of Mars that is visible from Earth. Mission design requires a communication link between the land/roving probe and the orbiter to track the status of the probe during the EDL process.

In view of the above considerations, the tentative landing area for the Mars exploration mission is 2 sub-area in the latitude range of 5° – 30° , as shown in Figure 2.

4.3 Mission profile

The Mars probe will be launched at the newly constructed Wenchang Satellite Launch Center. It will be launched directly into the Earth-Mars transfer orbit using the CZ-5 launch vehicle.

After separating from the launch vehicle, the probe will perform trajectory correction maneuvers, brake at periareon and then enter Mars' atmosphere. The probe will then enter an elliptic orbit around Mars with an orbital period of approximately 10 d. During the early stages of orbiting Mars, the probe will perform orbit maneuvers and enter an elliptic parking orbit with an orbit period of approximately 2 d. Then, the probe will perform orbit maneuvers to lower the orbit altitude

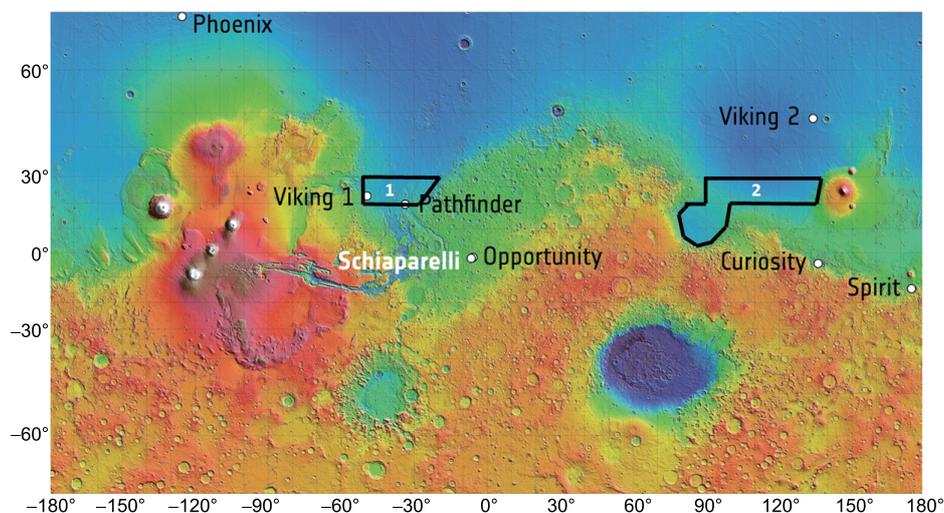


Figure 2 Tentative landing area on Mars.

and release the landing/roving probe. Subsequently, the orbiter will then enter a higher orbit for relay communications.

The landing/roving probe will enter the Martian atmosphere after separating from the orbiter. After multiple stages of deceleration (involving aerodynamic shape, parachute and engine) and buffering the landing legs, the landing/roving probe will land softly on the Martian surface. The Mars rover will then leave the landing platform and begin its scientific exploration.

Initially, the primary work of the orbiter is to provide a relay communication link to the Mars rover while performing scientific exploration. After operating for 90 Martian days, the orbiter will maneuver to enter a remote sensing orbit. The primary work of the orbiter then changes to scientific exploration while maintaining a relay communication link to the Mars rover.

During the mission, the ground application system will receive scientific exploration data and perform data analysis and scientific research.

The mission profile of the Mars probe is divided into 5 stages, as shown in Figure 3.

Stage 1: Earth-Mars transfer stage. This stage will take approximately 7 months. The probe will complete a series of trajectory correction maneuvers (TCMs), navigation practices and antenna calibrations.

Stage 2: Mars orbit insertion stage. This stage will take approximately 10 d. The probe is inserted into a nearly polar orbit with a period of 10 d.

Stage 3: Mars orbit parking stage. This stage will take approximately 2–3 months. The primary work includes com-

pleting orbit maneuvers to adjust the inclination and period and perform early detections of the landing area.

Stage 4: Deorbit and landing stage. This stage will take approximately 5 h. The primary work includes completing the separation of the two probes, the orbit-raising maneuver of the orbiter, EDL control of the landing/roving probe and safe landing on the Martian surface.

Stage 5: Scientific exploration stage. After landing, the Mars rover will extend its solar panels, establish direction control of the Earth-point antenna and report its initial status. The orbiter will be located in a relay communication orbit to support the rover's scientific exploration of Mars. When the 90 Martian day lifetime of the Mars rover ends, the orbiter will perform an orbit maneuver to enter a remote sensing orbit to perform scientific exploration for approximately 1 Martian year.

4.4 Preliminary configuration of the scientific payload

The probe will complete global and comprehensive exploration from its orbit. The preliminary configuration of the scientific payload includes a moderate resolution camera, a high-resolution camera, a subsurface detection radar, a mineral spectrum detector, a magnetometer and a particle analyzer.

Additionally, the probe will perform high-accuracy and high-resolution investigations of key areas on the Martian surface by roving exploration. The preliminary configuration of scientific payload includes a multi-spectral camera, a subsurface detection radar, a surface component detector, a surface magnetic field detector, a climate detector, and a na-

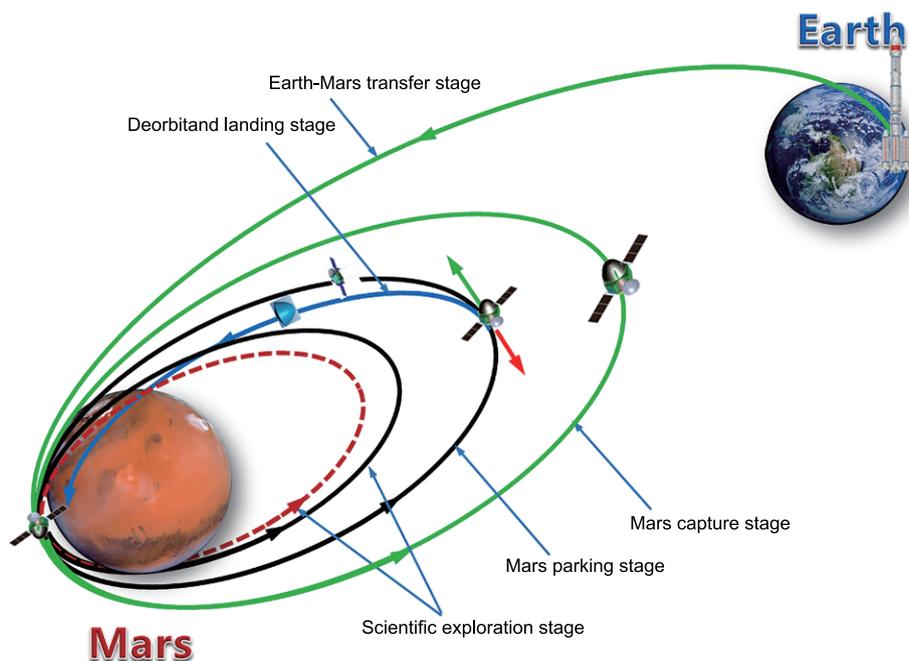


Figure 3 Mission profile of the Mars probe.

vigation and topography camera.

The payload configurations and the corresponding scientific missions are listed in Table 1 and Table 2.

5 Mission difficulties and characteristics

Orbiting, landing and roving will be accomplished in the first Mars exploration mission. Overall, the mission is quite ambitious and includes significant technological advancements. The probe has a long flight time with multiple essential aspects that must be coordinated without flaw. Additionally,

the requirement of coupling the design of multiple targets is high. Compared to Lunar missions, the technical characteristics of the Mars mission are listed in Table 3.

The major difficulties in the system design of the Mars probe for this mission include the following.

5.1 The mission is ambitious with significant technological advances

The risk of the Mars exploration mission is high, especially during landing. Although the starting point of China's first Mars mission is ambitious, the success rate for the early stage

Table 1 Scientific missions and payload configurations of the orbiter

Scientific mission	Payload
Detection and analysis of the Martian ionosphere and the interplanetary environment.	Mars magnetometer; Mars ion and neutral particle analyzer; Mars energetic particle analyzer
Water and ice detection on the Martian surface and underground.	Subsurface detection radar
The type, distribution and structure of Martian soil.	Subsurface detection radar; Mars mineral spectrum detector
Detection of the topographic characteristics of Mars.	Moderate resolution camera; High resolution camera; Subsurface detection radar of the orbiter

Table 2 Scientific missions and payload configurations of the rover

Scientific mission	Payload
Acquire topographic data of Mars, including characteristics such as slope, waviness and roughness.	Navigation and topography camera
Acquire multi-spectra images of the landing and roving areas. Acquire material composition and its distribution on the Martian surface.	Multi-spectra camera
Detect the soil thickness and ice layer structure in the roving area. Acquire ultra-bandwidth full-polarization echo data of the Martian surface and subsurface. Detect the subsurface structure in the roving area and acquire subsurface geological structure data.	Subsurface detection radar
Analyze the composition of the chemical elements of Martian surface materials. Perform mineral analysis and rock recognition on the Martian surface.	Martian surface component detector
In conjunction with the orbiting survey, detect and study the Mars spatial magnetic field, acquire the current of ionospheric dynamo by inversion, and study the conductivity of the Martian ionosphere.	Martian surface magnetic field detector
Measure the temperature and air pressure on the Martian surface. Perform <i>in situ</i> measurements of wind field parameters on the Martian surface.	Mars climate detector

Table 3 Differences between the Mars and Lunar missions

Characteristics	Lunar mission	Mars mission
Longer flight distance	400 thousand kilometers	400 million kilometers
Higher requirements for independency	1.35 s for one-way	22 min for one-way
Complication of mission environment	Lunar surface is highly vacuum with intense solar power	Thin atmosphere and dust on Mars, and the uncertainty of environmental parameters is high. The surface terrain is rough and the solar power is weak.
Higher requirement of deceleration	Decelerate 1.7 km/s from a height of 15 km to the lunar surface. Time spent is approximately 12 min [7]	Decelerate 4.8 km/s from a height of 125 km to the Martian surface. Time spent is approximately 7 min.

of the mission may be low. The entry mass is less than that of the Mars Science Laboratory mission of the United States, which was launched in 2013. The size and exploration capability of the orbiter is almost on par with the advanced Mars orbiting missions launched this century. The risk of this mission is high, and the reliability of the hardware and software must be exceptional. Multi-target exploration raises many difficulties in coupling system design. For example, the orbiter must accomplish multiple autonomous orbit maneuvers with only one uplink input, coupling entry and communication relay may lead to an insufficiency of data during the early stages of landing, and the design of the orbiter for remote sensing and relay communication is difficult to balance.

5.2 Mission environment is new with high uncertainty

The Mars environment includes relatively unexplored features such as a thin atmosphere, wind field, topography, dust, thermal environment, and gravity field, to name a few. The environmental characteristics are complicated and highly uncertain [8,9]. Among them, the effect of the atmosphere, wind field and topography on soft landing, the effect of topography and dust on the mobility and energy consumption of the Mars rover, and the effect of low temperature throughout the Martian night on the survival of Mars rover are directly related to the success of the mission. The Chinese technical background in these aspects is weak and first-hand experience and data are lacking, which greatly raises the difficulty in its probe design.

Despite the constraints brought by this new environment and its associated uncertainty, system design must also satisfy a variety of requirements such as lightweight design, long-range telecommunication, strong constraints on the flight profile, high integration of equipment. These requirements create many challenges in the configuration design, aerodynamic shape, separation strategy, control strategy of entry and landing and the Mars rover exploration on the Martian surface.

5.3 Multiple critical aspects with high difficulty

Compared to the three Lunar missions involving “orbiting”, “landing” and “roving”, the first Mars mission encompasses much greater technical advances and many new technologies. There are many “critical and unique” aspects that may affect the success of the mission, such as precise separation, EDL, movement on the Martian surface and interplanetary telecommunication. These aspects are all interdependent, increasing the risk in the mission.

By implementing the Lunar exploration missions, China has accumulated a technical foundation in extraterrestrial orbiting, landing, roving, and hypervelocity reentry [7]. However, the Mars exploration mission has many other technical difficulties that must be overcome. For instance, a novel aerodynamic shape must be implemented in Mars entry, which is related to the theoretical research of the composition of the Martian atmosphere and rarefied flow analysis. In this regard,

the Disk-Gap-Band (DGB) parachute [10,11] will be used for the first time; however, the theoretical analysis, design standard and experimental verification of the parachute are essentially nonexistent at present. The requirements of thermal control, obstacle avoidance and independency are very high and require the application of a new type of aerogel thermal insulation material and an active suspension that is adapted to the Martian topography. Stronger capabilities of environmental sensing and autonomous planning are also required. These key technologies will be very challenging to develop.

5.4 Intense verification and complicated experimentation

To ensure the sufficiency and effectiveness of verification, various experiments must be completed in addition to the normal mechanical and thermal experiments. Specialized experiments for the subsystem level include investigating the subsonic/transonic/supersonic performance of the parachute and wind tunnel experiments involving the aerodynamic shape. Specialized experiments for the system level include hovering, obstacle avoidance and slow descent experiments, separation and release experiments, landing impact experiments, and landing stability experiments, among others. Additionally, several ground tests are required for the Mars EDL process, the time sequence verification and the parachute, such as the rocket flight test of the parachute and detachment tests of the front-shield/backshell under low dynamic pressure. Moreover, the current lack of understanding of the Martian environment and the difficulty in simulating the actual Martian environment lead to the difficulties in some of these highly specialized experiments. Indeed, some of the Martian environment can hardly be simulated, such as the low enthalpy/low density/Martian atmosphere composition and the combination of supersonic/low density/low dynamic pressure.

6 Key technologies of the mission

The long distance and complex environment for Mars exploration lead to significant technical challenges and high risk in its implementation. A series of new technologies will be developed based on the Lunar exploration. Autonomous control, telecommunication, EDL and new structure and mechanism are the key technologies that will be developed and mastered.

6.1 Telecommunication technology

The longest distance to Earth in the Mars exploration is 400 million kilometers. The lowest reception level is -150 dBm and the signal has a large Doppler frequency shift. Achieving reliable capture and tracking with such a low signal level is one of the key technologies that must be improved. To adapt to the wide range variation of this mission, the design

of adaptive demodulation in multiple steps is needed to satisfy the requirements of various distances and antennas. Realizing demodulation in multiple code rates and at the low code rate of 7.8125 bps is a technical difficulty.

Moreover, compared to Earth relay satellites, the communication link between the orbiter and the landing/roving probe suffers from bad channel conditions and a complicated communication environment. The design of a reliable protocol and link is required to improve the capability of transferring data and command between the landing/roving probe and orbiter nodes. Under the constraint of system resources, communication of the Mars rover to Earth will primarily occur via the link between the Mars rover and the orbiter. The Consultative Committee for Space Data Systems (CCSDS) link-protocol applied in the communication between the probes is related to the technologies of retransmission, various frame sizes, code rates, and an adaptive code rate. To accomplish the relay communication both during and after the landing procedure, the development of a new backshell antenna and relay antenna is required. The adaptation to extreme thermal conditions, the high target requirement of the antenna pattern, and the size constraint of the antennas are other technical difficulties that must be overcome.

6.2 Autonomous control technology

Regarding the long telecommunication delay, low accuracy in long range orbit, and the long duration of Sun outage, the Mars probe is required to have a very strong self-management and autonomous navigation capability, including the technologies of self-management, autonomous navigation and control, high-accuracy navigation sensors and flight control with large time delays.

Clearly, the Earth-Mars distance is much larger than the Earth-Moon distance in the Mars exploration mission. Ground-based orbit determination accuracy is significantly reduced as the distance increases. Preliminary estimates of the orbit determination accuracy and velocity measurements close to Mars are approximately 100 km and 1–10 m/s, respectively. Especially during the Mars capture and orbiting stages, the requirements of the Mars pointing accuracy and autonomous maintenance of orbit safety are difficult to satisfy using the results of ground-based orbit determination alone. Therefore, the probe must have the capability of autonomous navigation and control to ensure its safety and the completion of the major engineering outcomes. Additionally, the periareon altitude of the capture orbit should be sufficiently low to conserve enough propellant to complete the entire mission. Therefore, high accuracy autonomous navigation and orbit control are required to ensure the safety of the braking procedure.

During the Mars mission, each Sun outage will last for more than 20 d. During this period, the uplink and downlink of the probe will be worse because of Sun noise and the

ground telemetry, track and command (TT&C) station and the ground application station will not be able to establish connections with the probe. For these reasons, the probe is required to have a strong self-management capability. Moreover, the probe must be able to accomplish some of the engineering and scientific tasks independently in the event of emergencies.

The Mars rover exploration cannot fulfill timely telecommunications as the Chang'E-3 rover. The Mars rover is required to have excellent autonomous navigation capability and movement and a longer traveling distance for each navigation period. Meanwhile, selection of the navigation target site demands a higher requirement for ground telecommand. To achieve long distance travel of the Mars rover within the complex Martian environment and to arrive safely at the designated position, the ground telecommand and autonomous operation capability of the Mars rover must be considered systematically to reasonably determine the operation and control strategy of the Mars rover.

6.3 EDL technology

Martian atmospheric entry and landing will be China's first landing on an extraterrestrial planet with an atmosphere. Because of the low density of the Martian atmosphere, the distinct atmospheric compositions between Mars and Earth, the lack and uncertainty of atmospheric research data and the special requirement of aerodynamics during the Mars landing exploration mission, the Martian EDL process will undoubtedly encounter many technical difficulties.

1) Aerodynamic technology. The shape of the Chinese reentry capsule and the shape of the Mars lander of other countries cannot be directly applied in the mission environment of the Mars EDL process. The design of a new aerodynamic shape, specifically a half-ballistic shape, is required. Since there is no domestic research on Martian atmospheric models and chemical reaction models, corresponding databases must be constructed and verified based on international data. The domestic research on the error (uncertainty) of the aerodynamic data has not yet formed as a systematic theory. Based on its own engineering experience, each mission develops an adaptive estimation algorithm. The shape of the Mars landing/roving probe is new, and the EDL environment is different from that encountered in reentering Earth. Therefore, the configuration of the aerodynamic data errors has new features and cannot fully implement the estimation method of the ShenZhou spacecraft and the reentry capsule of the 3rd phase of Lunar Exploration Program as a reference. The error accuracy requirement is high and difficult to realize. Regarding the thin Mars atmosphere (only 1% of Earth's atmosphere), developing innovative technologies to design a large blunt aerodynamic shape with large drag characteristics and a high volume fraction are required.

2) Thermal protection technology. The aerodynamic heating condition in the Mars entry process has features of medium/low enthalpy, medium/low heat flow and chemical imbalance. Moreover, the major component in the Martian atmosphere is CO_2 , which is significantly different from Earth's atmosphere. The ablation characteristics of the thermal protection material during Martian entry are not well studied domestically, and the difficulties of test verification and theoretical analyses of ablation are very large. In addition, the uncertainty of the aerodynamic thermal condition during the Mars entry process is high and the laminar flow may change to turbulent flow, which poses a great challenge to the design of a lightweight thermal protection system.

Parachute deployment will be supersonic during the Mars entry and landing process, which leads to some problems in parachute design, including the instability in parachute deployment and deceleration, the decrease of drag ratio, etc. Moreover, the wake flow and shock wave of the fore body and the shock wave on the parachute will cause intense shimmy and surge on the parachute cord under supersonic conditions, which may damage the parachute sutures and the canopy. A big sail DGB parachute that can adapt to the conditions of low density and dynamic pressure must be developed.

6.4 Structure and mechanism technology

The densely distributed rocks and other obstacles on the Martian surface require a strong obstacle crossing and climbing capability of the Mars rover. While the Mars rover carries on with the exploration mission, it must move to different locations. Compared to the Lunar surface, the distribution of rocks and other obstacles on the Martian surface is denser. The movement of the Mars rover is mainly based on autonomous control. The soil on the Martian surface may collapse and cause the wheels to become stuck. Such a condition will lead the permanent loss of mobility of the "Spirit" Mars rover. Therefore, the Mars rover must have strong obstacle crossing and climbing capability and must be able to recover from dangerous conditions that it may encounter, such as those mentioned above. Because of the new environment on the Martian surface, the key technologies of mobility with active suspension, independent driving and rotating capability and adaptation to complicated topography are required for this mission.

Several new aspects exist in the Martian EDL process, such as the supersonic parachute deployment and parachute pop-up impact. Its impact time is close to the fundamental frequency of the probe and may lead to an amplification of the dynamic load. It is the major load in the design of the Martian landing/roving probe structure. In addition, the main structure is at a high temperature under the load conditions; therefore, coupling the mechanics and thermal condition design effectively should also be considered. Compared with the reentry capsule of the ShenZhou spacecraft and the metal

capsule structure of the reentry capsule of the 3rd phase of Lunar Exploration Program, the structure of the Mars landing/roving probe is the first all-composite structure to be developed domestically. The size of the structure is large and the requirements of the forming process accuracy and reliable thermal protection are high. New problems of the lightweight design of the load-carrying structure, the thermal protection structure and the manufacturing process must be addressed and solved.

7 Expected results

The first Mars exploration mission is complicated and will develop many key technologies. Without question, this mission will promote innovation and development of a series of scientifically related technologies.

1) Technically, the mission will realize the arrival at an extraterrestrial planet 400 million kilometers away from Earth for the first time, master the key technologies of deep space exploration, such as the precise control of orbit over a long distance, autonomous navigation and control, large-delay communication (40 min) and interplanetary telecommunication and improve the Chinese deep space exploration capability from 400 thousand kilometers to 400 million kilometers.

2) The mission will realize a soft landing on an extraterrestrial planet for the first time and revolutionize new types of entry technologies including a large, blunt aerodynamic shape (70°), supersonic (2 Ma) DGB parachute and power descent control (0.3 g). The high-precision autonomous obstacle-avoidance landing technology will be used for the first time internationally, and the deep space exploration capability of China will be expanded from a planet with weak gravity (1/6 g) and no atmosphere to a planet with a large mass (2/3 g) and atmosphere.

3) The mission will realize autonomous roving exploration on the surface of an extraterrestrial planet for the first time, master the autonomous roving and surviving technology under a complicated topography and climate conditions, and improve the roving capability on a planet's surface from a "remote control" to a "local route fully autonomous" model. The realization of roving on the Martian surface will promote the development of artificial intelligence, autonomous control, mechanical and electrical integration and remote science.

4) Scientifically, the Mars orbiting and landing/roving exploration mission will acquire the distribution of Martian soil and the structural layer information for the first time on Earth. The electrical conductivity, the current distribution and the wave characteristics of plasma of the Mars ionosphere will be detected. The 3-dimensional distribution of the radiation spectrum and the distribution of the energetic particles in the Martian atmosphere will be studied, and biologies and physics experiment will be conducted on the Martian surface.

5) Additionally, several results will become the highlights of Chinese Mars exploration, such as the very low frequency (VLF) radio measurements in the Earth-Mars transfer process, 100 m-resolution Mars images and local 10 cm-resolution images, the vertical structure of the neutral component in the Martian atmosphere, the precise detection of the water escaping process in the Martian atmosphere, confirmation and distribution of underground water and ice in the middle and high latitude regions on Mars and the water and ice distribution at the polar regions.

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