Zhurong: Features and mission of China’s first Mars rover

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On May 22, 2021, at 10:40 am (Beijing Time), China’s Zhurong rover successfully reached the Mars surface and began its exploration. China is only the second nation to have conducted a successful soft landing and exploration of the red planet. The Mars probe consists of an orbiter and landing rover. The spacecraft includes an entry module consisting of a back shell, landing platform, and outsole, as well as a rover (Figure 1). Before release, the orbiter, which carries the landing rover, completed the Earth–Mars orbital transfer and an orbit reduction maneuver. After a nearly 3.5 h flight, the landing rover and orbiter entered the Martian atmosphere, landing on the planet’s surface after a multi-stage deceleration, and ramp mechanism expansion. Shortly after detaching from the landing platform the rover began its mission.

Mission constraints and design features of the rover

Mars is quite a distance from Earth. Its surface is both complex and frigid. Compared with the lunar rover,1 the Mars mission has vastly more stringent requirements for the rover’s communication abilities, thermal controls, mobility, and other various capabilities.2 According to the complex characteristics of the mission, it was designed to obtain as much scientific data as possible, while ensuring its safety.

Communication constraints and design

The communication window between Mars and Earth is limited. After landing on Mars, the visible arc between the rover and Earth is from about M04:30 to about M16:00 every Martian day. During this time window instructions can be sent from Earth to the rover’s X-band omni-directional antenna, but the throughput can be as low as 7.8125 bps.

To solve the rover’s communication problem, its communication system was based on the successful Chang’e-4 mission. Here a loop relay communication mode was employed, as well as a UHF band to facilitate two-way communication. The orbiter operates in a relay orbit, about 10 min near the Mars arc, which is around noon, and about 5 h during the Martian night.3 Near-Mars arc communication can reach speeds of Mbps, and is used to transmit real-time and delay telemetry data, image and detection data, and log follow-up rover work instructions at the same time.

Temperature constraints and design

The temperature on the Martian surface is below −100°C. To resist such a frigid temperature, an active and passive thermal control system was adopted. The rover is equipped with a solar window to collect heat during the day, which is then used to raise the cabin temperature at night. The rover uses active thermal control measures at night to ensure that the equipment in the cabin reaches the required ambient temperature. In addition, the passive thermal insulation of “aerogel + CO2 isolation” has also been implemented. With limited active thermal control resources, heat leakage is decreased by reducing heat conduction, isolating radiation heat leakage, and “eliminating” convection in the cabin, thus ensuring that the cabin remains at an optimal temperature.

Mars rover extravehicular navigation obstacle avoidance cameras, multispectral cameras, and other key equipment use active thermal control to ensure that their storage temperature meets the requirements. Various other extravehicular equipment must also be able to withstand extremely low temperatures.

Energy constraints and design

The average solar radiation intensity in the Martian orbit is about 43% of that near Earth. The complex environment with its powerful atmospheric
winds leads to a great amount of dust being kicked up on the Martian surface, which results in elevated energy consumption.

To improve energy efficiency, maximum power point tracking, which improves the efficiency of solar cell power generation, was employed. To reduce the influence of dust on solar cell power generation efficiency, a super thin solar film was used in conjunction with a special anti-dust coating, resulting in a dust removal efficiency of over 86%.

To adapt to the various lighting conditions on the Martian surface, the rover has been designed with a dormancy and wake-up mode. If a sandstorm comes, the rover will power off to prevent battery drain, and will remain “asleep” until generating power and temperature simultaneously reach optimal conditions. This is to ensure that the power and equipment are working at the appropriate temperature.

Terrain constraints and design

The surface of Mars is rugged. The coverage of rock is about twice that of the moon. To ensure safe movement of the rover, it is designed with a strong obstacle-surmounting capability. The Mars rover employs an active suspension, which is based on a main and auxiliary rocker arm suspension. The clutch is installed at the connecting point of the main rocker arm. The functions of controlled lifting, lowering, wheel lifting, and contraction of the suspension can thus be realized to improve the extrication ability of the rover. When a single wheel sinks, the rover can be extricated by employing the single wheel lifting function. When all wheels are caught, it can be extricated by suspension contraction, and when the rover body collides with a rock the suspension can be raised to clear the obstruction.

Typical work process design

To save energy, the rover is mostly in standby mode, which keeps the computers on and the other equipment working intermittently.

According to the arc of visibility, the mission cycle template is run on the rover, and the measurement and control equipment are independently switched on and off. During the Martian afternoon, the omni-directional X-band receiver is turned on for about 10 h, adapting to the arc of visibility between the rover and Earth to maintain a basic uplink channel. At noon on Mars, the UHF band receiver is turned on for about 1 h, adapting to the arc of visibility between the rover and Earth to maintain a basic uplink channel. At noon on Mars, the UHF band receiver is turned on for about 1 h to adapt to the near-Mars arc of the rover and orbiter. During the Martian night, the UHF band receiver is turned on for about 5 h to adapt to the remote arc section of the rover and orbiter.

The primary work period of the rover is set between M11:00 and M15:00, when the ambient temperature is highest and no additional heating is needed. Every Martian morning, delay instructions for the rover are sent via the orbiter. Around noon, the orbiter relays instructions through a UHF transceiver to the rover for execution. During the Martian night telemetry status is sent to the orbiter via UHF before being forwarded on to Earth.

Exploration mission

To carry out high-precision and high-resolution exploration of key areas on the Martian surface, the rover is equipped with six scientific payloads, including a navigation camera, multispectral camera, subsurface detection radar, surface composition detector, magnetic field detector, and meteorological instruments (Figure 1).

The exploration mission is based on the following aspects:

1) Both the navigation and multispectral camera detect the various mineral and rock types in the survey area, aiding the identification and mapping of surface morphology and material type distribution.
2) The subsurface detection radar identifies the soil structure in the survey area, and collects data on various soil types, weathering and deposition characteristics, water/ice content, as well as stratification structures.
3) The surface composition detector analyzes the chemical composition of the Martian surface as well as mineral analysis and rock identification. Chemical analysis is reliant upon quantitative analysis of laser-induced breakdown spectroscopy spectral data. Mineral analysis and rock identification is conducted mainly via short-wave infrared spectroscopy.
4) The magnetic field detector senses the magnetic field in the survey area. It determines the magnetic field index, observes the Martian space variation magnetic field, and inverts the Martian ionospheric generating current.
5) The meteorological instruments measure temperature, pressure, and wind speed/direction, as well as sound on the Martian surface.

In summary, China’s initial Mars rover mission accomplished its goal of carrying out mobile and scientific exploration of the Martian surface and sending blocks of data back to Earth for analysis. In the future the rover will face increasingly complex challenges as it continues to collect valuable data.

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DECLARATION OF INTERESTS

The author declares that there is no conflict of interest.