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MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

The Mars-94 and Mars-96 Missions [and Discussion]

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The Mars-94 and Mars-96 missions

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The main goal of Solar System studies in Russia for the next 10–15 years is Mars and the Mars-94 project is the first stage of this long-term space programme. In October 1994 it is planned to launch a spacecraft with the following components onboard: an orbiter, two small autonomous stations to be landed on the surface of Mars and two penetrators to analyse the underlying surface layers. The main scientific objectives of this mission are to investigate the evolution and contemporary physics of Mars, and to make, using various methods, a wide range of comprehensive studies of those physical and chemical processes which took place in the past and which continue there now. The payload of the Mars-94 orbiter includes 23 scientific instruments to study the Martian surface, the inner structure of the planet, its atmosphere, and its plasma envelope, as well as instruments for astrophysical studies. The next stage of the programme is a mission to Mars in 1996. At present the Mars-96 project includes a spacecraft with an orbiter, a Martian rover, a balloon, penetrators and small stations. A short description of the scenario, payload, and scientific objectives of these missions is presented in this paper.

1. Introduction

This paper differs from others presented at this meeting because it is devoted not to a review of results from space missions but to a description of a future mission. The appearance of this paper in the programme of the meeting is perhaps justified by the fact that the Mars-94 mission is the only planetary mission to be launched this year.

The Mars-94 project is the first in the programme of investigations of Mars accepted by the Russian Academy of Sciences and Space Agency as one of the cornerstones of the Russian space programme. This project intends to put a spacecraft into an elliptical orbit around Mars and to deliver two small stations and two penetrators on to the surface of Mars. The next step of the programme is the Mars-96 project, which includes an orbiter, a balloon to be flown in the Martian atmosphere and a Martian rover to travel on its surface. The scientific objectives of these two missions are similar. A short description of the scenario, payload, and scientific objectives of these missions is presented below.

2. Description of the mission

Mars-94 will be launched on a Proton rocket from Baikonur, Kazakhstan Republic in October 1994. Figure 1 provides an overview of the mission. After an

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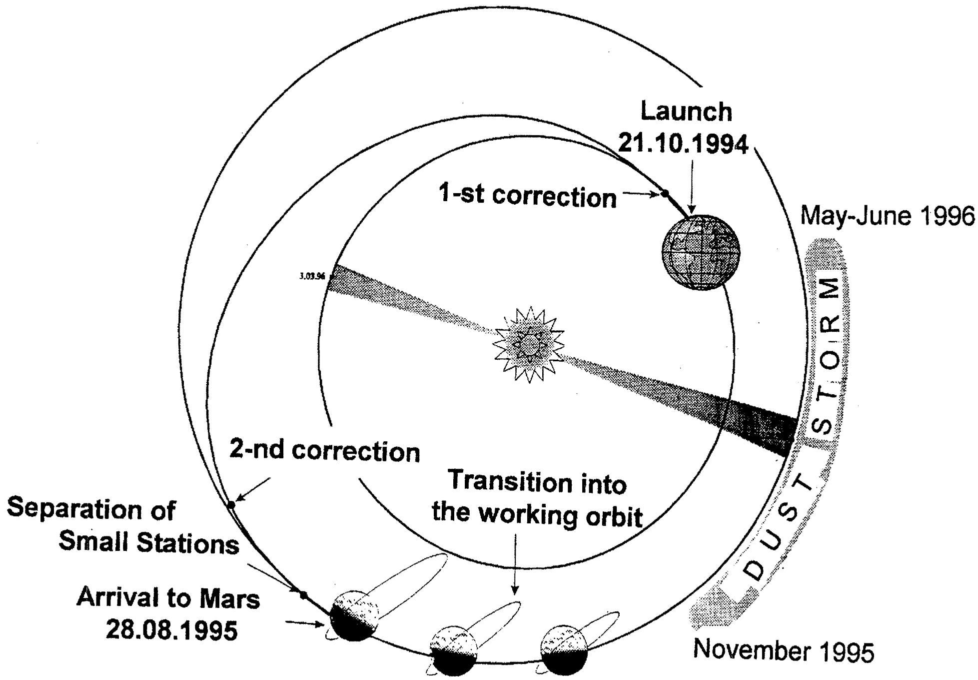

Figure 1. Overview of the mission.

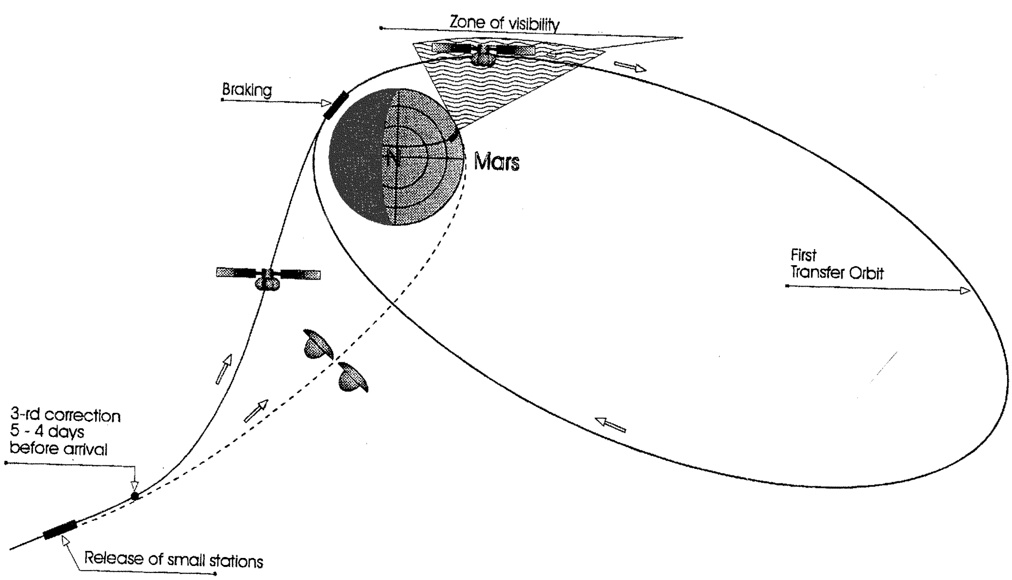

Figure 2. The arrival at Mars and the delivery of the small stations.

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Table 1. *Spectral coverage and resolution for the Mars-94 instruments for surface and atmosphere studies*

instrument	description	coverage	resolution
HRSC	stereoscopic TV camera	0.4–1.0 μm	$\Delta\varphi = 8''$
WAOSS	stereoscopic TV camera	0.4–0.7 μm	$\Delta\varphi = 64''$
OMEGA	mapping spectrometer	0.35–5.2 μm	$\Delta\varphi = 4'$
PFS	Fourier spectrometer	1.25–4.5 μm	$\Delta\varphi = 2.6°$
		6–45 μm	$\Delta\varphi = 4°$
TERMOSCAN	mapping radiometer	0.5–1.0 μm	$\Delta\varphi = 1'$
		8–13 μm	
SVET	mapping spectrophotometer	0.26–0.9 μm	$\Delta\varphi = 8'$
		1.05–27 μm	
SPICAM	optical spectrometer	0.2–0.8 μm	$\Delta\varphi = 2'$
		1.8–5 μm	$\Delta\varphi = 5'$
		0.11–0.4 μm	
		0.936 μm	
UVS	UV spectrophotometer	1215.3 Å	$\Delta\varphi = 2°$
		1215.7 Å	
		584 Å	
		1304 Å	
		834 Å	
LWR	long-wave radar	0.17–5 MHz	
	GRS	gamma-ray spectrometer	0.2–10 MeV
NEUTRON	neutron spectrometer	0.01 eV–3 MeV	
MAK	mass spectrometer	1–60 a.m.u.	

eleven-month transit, the spacecraft will be put into an elliptical three-day transfer orbit about Mars. Four to five days before the final approach to Mars, two small stations will be separated from the bus and delivered on to the surface of the planet. The arrival at Mars and the delivery of the small stations is depicted in figure 2. The spacecraft will carry two penetrators which will descend to the Martian surface during the first month of orbiting. The descent of the penetrators is illustrated in figure 3. After several manoeuvres a working orbit, which will have a 300 km pericentre, a period of about 15 hours and an inclination of 100°, will be achieved. Evolution of the orbit during the mission lifetime will make it possible to cover most of the surface of the planet for TV-mapping and other surface and atmospheric experiments, and to cover most of the Martian environment for plasma and plasma-wave experiments.

The spacecraft flight configuration is shown in figure 4. It has a three-axis stabilization system and two platforms intended for pointing and stabilizing several optical instruments. Table 1 provides a summary of the instruments mounted on the orbiter. The payload includes 12 instruments for studying the Martian surface and atmosphere, 7 instruments for studying plasma, and 3 instruments for astrophysical studies. Additionally, several instruments mounted on the 2 small stations and the 2 penetrators will study surface and atmospheric parameters *in*

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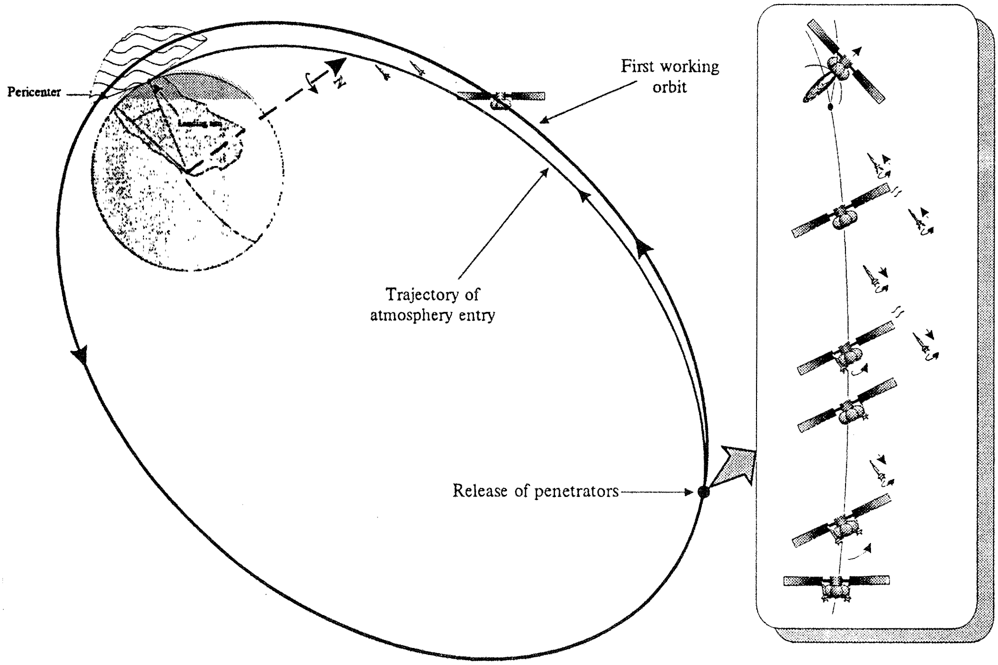

Figure 3. The descent of the penetrators.

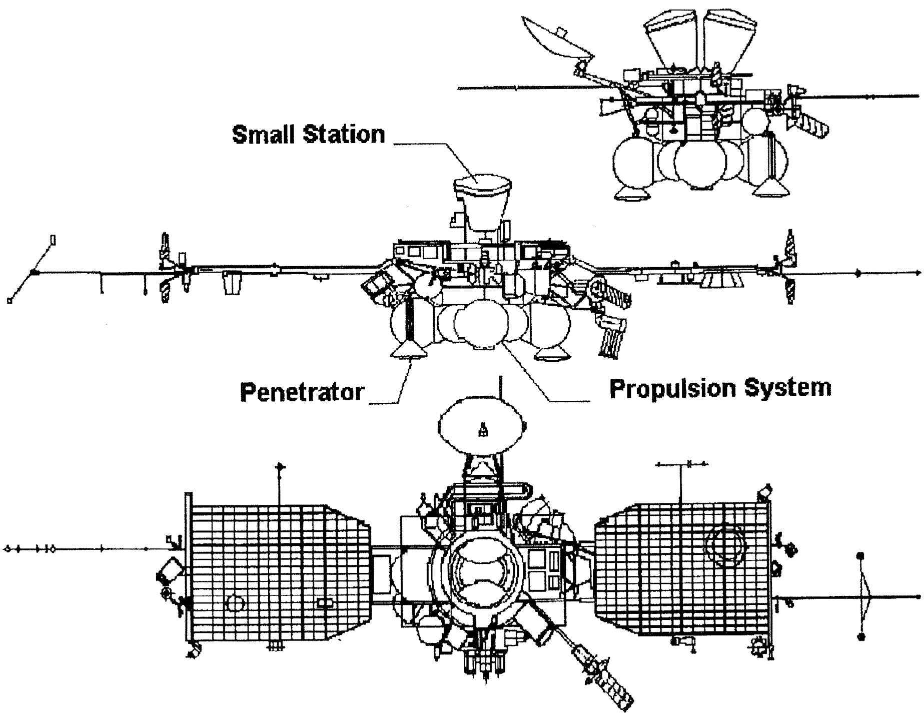

Figure 4. The spacecraft flight configuration.

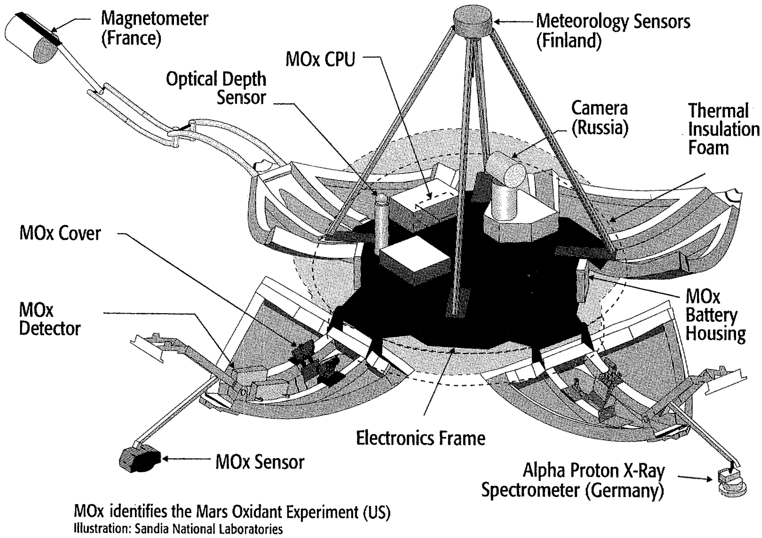

Figure 5. The small station configuration.

situ. Figure 5 shows the small station configuration, which includes six instruments, on the Martian surface, and figure 6 shows a section of the penetrator. When the probe impacts on the surface at a velocity of 80 km s^{-1}, the forebody and after-body will separate. The penetrating part of the probe forebody carrying the scientific and housekeeping instruments will enter the regolith down to 5–6 m. Scientific studies begin after penetration. Information from the small stations and the penetrators will be transmitted to the orbiter and then to Earth.

The main component of the Mars-96 project will be a lander, including a balloon station to be flown in the Martian atmosphere, and a rover to be delivered to a predetermined site on the planet's surface.

The balloon will fly at an altitude of *ca.* 4 km during the Martian day-time and will return to the surface at night, as illustrated in figure 7. The duration of the flight will be about two weeks, during which time it will cover more than 2000 km. Scientific instruments will be installed in the gondola and on the guide rope. The payload will include a TV system, a magnetometer, a meteorological complex, a laser altimeter-aerosol profiler, a gamma-ray spectrometer and a radar for subsurface sounding.

The Mars rover will carry a TV system with panoramic and wide-angle cameras, a gas chromatograph with pirolis, a quadrupole mass spectrometer, a Mössbauer spectrometer, an alpha-particle spectrometer, visual and infrared spectrometers, low-frequency electromagnetic sounding instruments and a meteorological complex. Several instruments will be mounted on the robotics arm of the rover. The total mass of the rover will be 75 kg. A photograph of a rover prototype taken during tests is shown in figure 8.

3. Science objectives

The primary objectives of the Mars-94 mission are to investigate the evolution and present-day geophysical, chemical, geological and atmospheric states of the

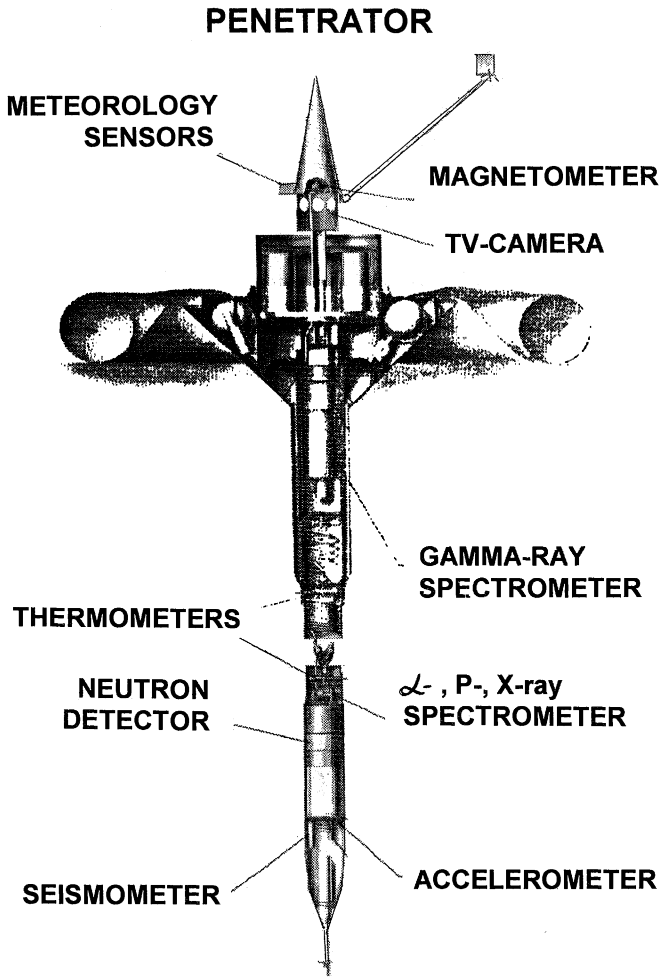

Figure 6. A section of the penetrator.

planet and its interaction with the interplanetary environment. Results of previous missions to Mars and a summary of what is known about this planet are presented in Kieffer *et al.* (1992). New data in these fields will help to improve our knowledge, not only of Mars itself and the terrestrial planets in terms of their comparative planetology, but in the much broader context of the origin and evolution of all the planets. We hope to improve our knowledge of Mars in order to create a more accurate engineering model of the surface and atmosphere for future more intelligent robotic missions and manned missions to Mars.

Scientific experiments within this project should help to find solutions to the following problems which can be presented in terms of geoscience, atmosphere science and plasma physics.

(a) *Geoscience*

(i) *Topography of the surface including high-resolution studies of the terrain*

Topography will lead to a more complete understanding of the geological processes that have affected the surface. One of the main questions is the nature

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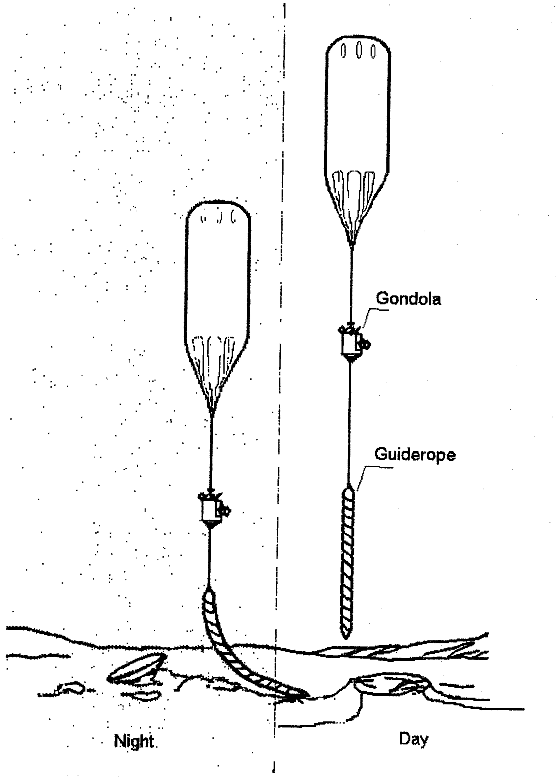

Figure 7. The operation of the balloon.

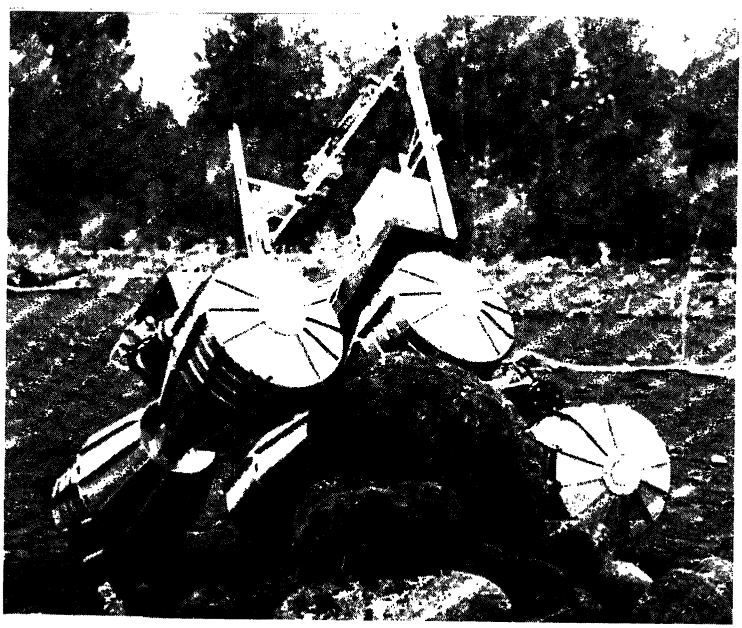

Figure 8. The Mars rover prototype.

and cause of the planet-wide dichotomy into southern old cratered highlands and northern young sparsely cratered plains. We need to determine the chemical and mineralogical differences between these two regions, how the crust and lithosphere differ beneath these regions, and what the nature of the boundary is.

A wide-angle stereoscopic TV camera (WAOSS) will provide global topography and will monitor the time variation of the surface conditions. The spatial resolution of this camera is about 100 m from an altitude of 300 km. A detailed topographic survey, multiband imaging and photometric studies of the surface using three-dimensional reconstructions of its relief with a spatial resolution of 15–20 m will be done using a high-resolution stereoscopic TV camera (HRSC). The TERMOSCAN mapping radiometer has both visible and infrared channels. It will provide data on the thermal inertia of the Martian soil, the diurnal and seasonal dynamics of the temperature regime, and will search for anomalous heat sources.

(ii) *The global chemical and mineralogical characteristics of surface materials*

Mapping data received by the visible and infrared mapping spectrometer (OMEGA), the planetary Fourier spectrometer (PFS), and the high-resolution mapping spectrometer (SVET) will lead to a better understanding of the distribution of the chemical elements and minerals on the Martian surface with respect to the age, origin, nature and weathering of the surface rocks, volcanic processes, and thermal evolution of the interior of Mars.

The ratio, K/U, of the abundance of the natural radioactive elements potassium and uranium, coupled with other elemental ratios measured by the gamma-ray spectrometer will provide important information on the bulk composition, an indication of the degree of differentiation of the planet, and estimates of the amount of volatiles, including water. Uranium provides an index for those elements that tend to condense from the solar nebula at high temperatures; potassium is an index for elements with lower condensation temperatures; yet both behave similarly in magmatic processes.

(iii) *The role of materials containing water and other volatiles; the cryolithozone and its deep structure*

A very interesting problem is the role of water, its form (absorbed, ice, water-containing minerals, etc.) on Mars, how water is cycled, and the distribution and dynamics of ice. Several optical onboard spectrometers and the neutron spectrometer will provide data on water content in the surface layer of the Martian soil. One of the objectives of the long-wave radar studies is to gather data on the underlying surface structure of the Martian cryolithozone: the depth, thickness and latitude distribution of permafrost.

(iv) *The problem of an intrinsic magnetic field*

This is the most debatable problem. Whether an intrinsic planetary field exists, and if so, what its magnetic moment is, remains an open question. The answer to this question will lead to an understanding of any planetary dynamo in the core at present and in the past, the interior structure of the planet, and the way in which Mars interacts with the interplanetary environment. Previous Martian missions and the Phobos mission did not answer this critical question. The orbiter, the small stations and the penetrators all carry magnetometers, which we hope will provide sufficient data on the parameters of the magnetic field in the Martian environment and on the surface of the planet.

(v) *A search for seismic activity caused by internal processes or impacts*

Another open question concerns the current activity of the Martian interior and surface: tectonics and impacts. To search for these effects seismometers are mounted on the small stations and penetrators.

(*b*) *The atmosphere and climatic monitoring of the planet*

(i) *The structure and dynamics of the atmosphere*

One of the main goals in the study of the dynamics of planetary atmospheres is to understand the response of atmospheric circulation to the factors that shape and drive it, especially rotation and heating. From this point of view it is very important to gather data on the present seasonal cycles of water, carbon dioxide and dust, as well as on the variations in the three-dimensional temperature field and the pressure at different space- and time-scales.

For this purpose several optical instruments mounted on the orbiter will provide data on the variation of atmospheric parameters. The planetary Fourier spectrometer, PFS, will gather data on local carbon dioxide band profiles which will help to construct the three-dimensional distribution of atmospheric temperature, the global mapping of winds and the characteristics of aerosols. The wide-angle and high-resolution stereoscopic TV cameras will provide a synoptic survey of Mars and global monitoring of the time variation of atmospheric conditions, in particular, the structure and movement of clouds, and changes due to dust storms. This information will form a basis for comparing the general circulation of the Martian and terrestrial atmospheres. By using a variety of dynamic models to explore similarities and differences between the two planets, we will gain a better perspective on atmospheric dynamics and how it is controlled.

(ii) *Direct studies of boundary layer processes*

The surface of Mars has undergone and continues to undergo extensive modifications as a result of aeolian erosion, redistribution of dust and weathering. The atmosphere also transports water and carbon dioxide between various surface reservoirs. The processes in the planetary boundary layer are due to the interaction between the atmosphere and the surface and play an important role in the study of the general circulation of the Martian atmosphere. Studies of these areas are the main goals of the meteorological instrument systems mounted on the small stations and the penetrators operating on the Martian surface. The meteorological instrument systems include a temperature sensor, an absolute pressure sensor, a relative humidity sensor, an optical depth sensor, an anemometer and a TV camera. These instruments will also measure the vertical structure of the atmosphere during the landing of the small stations.

(iii) *The origin and the evolution of the atmosphere*

The most effective method for studying the origin and evolution of the atmosphere is analysis of abundances and isotopic ratios of gases in the Martian atmosphere as well as volatile compounds trapped or frozen in the planet's soil. Fractioning of isotopes in atmospheric gases occurs primarily as a result of mass-dependent escape from the planet or as a contribution from nuclear processes.

Changes in isotopic composition can also occur as a result of the exchange of atoms between one molecular species and another, or between solid and gaseous forms of the same species, depending on the temperature and the relative abundance. The abundance of nucleogenic isotopes in an atmosphere is determined by the composition and outgassing history of the crust in the case of the decay of radioactive parents, and the histories of the planetary magnetic field and the atmospheric thickness in the case of spallation. Hence precise values of isotopic ratios of different gases provide important data on the origin and the evolution of the atmosphere, in particular, peculiarities of the atmosphere near volcanic mountains.

Mars-94 has several instruments for the measurement of abundances of minor constituents of the Martian atmosphere – water vapour, carbon monoxide, ozone, oxygen, hydrogen and helium – as well as for measurements of the variations in space and time of the isotope ratios O^{17}/O^{18}, Ne^{20}/Ne^{22}, Ne^{20}/Ne^{21} and Ar^{36}/Ar^{38}.

(c) *The plasma environment*

(i) *The interaction between Mars and the solar wind*

The nature of the interaction of the solar wind with Mars is perhaps the most challenging to understand. The cornerstone of this problem is the strength of the intrinsic magnetic field of Mars. For the case of a strong magnetic field (as for the Earth), the dipole field is a clearly identifiable obstacle. For non-magnetic planets with an atmosphere (as with Venus), the ionosphere is an obstacle for the solar wind. The description of the interaction of the solar wind with Mars is complicated for at least two reasons. First, the role of the intrinsic magnetic field of Mars as an obstacle may vary depending on the magnitude of the solar wind pressure. Second, the density of the Martian ionospheric plasma decreases gradually with altitude. These factors give rise to a variation in the characteristics of the interaction of the solar wind with Mars; the characteristics are jointly determined by the solar wind pressure, the interplanetary magnetic field and the presence of the neutral atmosphere in the interaction region.

So, to study the effects of the interaction of the solar wind with Mars, several instruments were included in the payload. These instruments will provide data on the magnetic fields, plasma waves, and the three-dimensional distribution and energy spectra of the main plasma components. The spacecraft's orbital evolution will make it possible to take plasma measurements in the solar wind region, and especially in the region of the interaction between the solar wind and Mars, to study the structure of the Martian magnetosphere and its boundary.

(ii) *Features of the Martian magnetosphere*

One of the most important features discovered by direct measurements during the Phobos mission is the dominance of the ionospheric ions (including oxygen) inside the magnetospheric cavity of Mars. Oxygen ions are up to ten times more abundant than protons in the Martian magnetosphere. This is clearly the most oxygen-dominated magnetosphere observed hitherto in the Solar System. A consequence of the interaction of the solar wind with Mars is the mass-loading of the solar wind by the extensive corona of planetary ions and the ionosphere of Mars. Ion 'pick-up' leads to loss of planetary ions, which implies that if Mars lacked

Table 2. *The Mars-94 instruments for plasma and astrophysical studies*

instrument	description
ASPERA	energy-mass ion spectrograph and neutral-particle imager
	energy range: $E_{\mathrm{i}} = 0.5$ eV–50 keV, $E_{\mathrm{n}} = 5$–300 keV, $E_{\mathrm{n}} > 10$ eV
FONEMA	fast omnidirectional non-scanning energy-mass analyser
	energy range: 20 eV–8 keV
DYMIO	omnidirectional ionospheric energy-mass-spectrometer
	$T_{\mathrm{e}} \sim 200$–10 000 K
MARIPROB	ionospheric plasma spectrometers
	$T_{\mathrm{e}} < 15\,000$ K
MAREMF	electron analyser and magnetometer
	$E_{\mathrm{e}} = 0.5$–2 keV
ELISMA	wave complex
	measurements: E_{xyz}, B_{xyz}, N_{e}, T_{e}
SLED-2	low-energy charged particle spectrometer
	$E = 20$ keV–several MeV
LILAS-2	cosmic and solar gamma-ray burst spectrometer
	energy range: 4 keV–1 MeV
	resolution: 1 ms (integral measure); 0.25 s (spectral measure)
EVRIS	stellar oscillation spectrometer
	spectral range: 300–800 nm
	limiting magnitude < 4 m
SOYA	solar oscillation photometer
	filter 845 ± 5 nm
	brightness resolution 10

a significant magnetic field in the past then the planet has been subjected to continuous atmospheric erosion through the interaction with the solar wind. To clarify these effects and estimate the value of atmospheric erosion through plasma processes the Mars-94 payload includes instruments for studying the atomic and molecular ion composition of ionospheric plasma.

(*d*) *Astrophysical studies*

The Mars-94 project includes several experiments which are not related to the investigation of Mars, but take the opportunity of interplanetary flight to achieve other specific aims. The instruments are listed in table 2.

(i) *Localization of cosmic gamma-ray bursts*

The main reason for undertaking these experiments is to create a long baseline for recording cosmic gamma-ray bursts, with the possibility of very accurate localization of their sources. The greater the distance between two gamma-ray detectors recording a cosmic gamma-ray burst, the smaller the error in localizing the source of the burst. If we can use one gamma-ray detector mounted on a near-Earth satellite and another detector mounted on the Mars-94 spacecraft the baseline will be of the order of one astronomical unit. In this case cosmic gamma-ray bursts can be located to an accuracy of about one second of arc. The main scientific objectives of the precision gamma-ray spectrometer (PGS) and the gamma-ray burst spectrometer (LILAS-2) are measurements of gamma radiation from gamma-ray bursts and powerful solar flares.

(ii) *Oscillations of stars and the Sun*

Data on the power spectrum of global solar and stellar oscillations will provide important information on their internal structure and dynamics. Solar oscillations have already been studied from ground-based and satellite observations. However, the capacities of these observations were limited by the effect of the Earth's atmosphere, the diurnal cycle and by the period of satellite revolution around Earth, which is close to periods of solar pulsations. Monitoring of the Sun and stars over several months of interplanetary flight is the optimal method of studying their oscillations. The Mars-94 spacecraft will therefore carry two instruments for recording the variability of radiation spectra: one instrument is the solar oscillation photometer (SOYA) and the other is the stellar oscillation photometer (EVRIS).

4. Concluding remarks

According to the mission preparation programme, the launch of the Mars-94 spacecraft is scheduled for October 1994. However, a number of problems, mostly associated with financial difficulties, were encountered during the last two years. The Russian Space Agency and the principal investigators will do their best to prepare the spacecraft and scientific instruments in time for launch in October 1994, but it may be that analysis of the results of ground-based testing of the spacecraft and the scientific instruments would lead to the decision to postpone the launch of the Mars-94 spacecraft till 1996. In that case there are two possibilities:

(i) In 1996 the ballistics of the spacecraft flight to Mars will differ from the ballistics in 1994. In fact, to put a spacecraft into a Martian orbit with the same parameters in 1996 would require more fuel than would be necessary in 1994; therefore the total possible mass of the scientific payload to be installed on the spacecraft would be proportionately reduced. To solve this problem, launching two similar spacecraft, with the scientific instruments shared between them, in 1996 could be the answer. Moreover, the launch of two spacecraft within one astronomical window would increase the reliability of the entire mission. The benefits of returning to a two-launch scheme for interplanetary missions is confirmed by recent planetary missions in both Russia and the U.S.A.

(ii) The other possibility is that if the launch of the Mars-94 spacecraft is postponed from 1994 to 1996, the launch of the Mars-96 mission could be rescheduled to the next astronomical window, 1998.

It has become clear that in the present economic conditions in Russia new organizational solutions should be sought for the preparation of large-scale projects such as Mars-94 and Mars-96, which are now national Russian projects involving scientific teams from about 20 countries. At the International Scientific Council meeting on the Mars-94 project in December 1993, the opinion was expressed that it would be expedient if the next project could indeed be an international collaboration, whose activities were financed from a fund established by the participants. Moreover, it should be borne in mind that international projects relying upon Russian space technology may still be significantly less costly, and the international status of the project would considerably strengthen its financial stability. It would be a sort of interim international space agency or consortium set up for a given project. Perhaps this would be a pattern for future cooperation.

The Mars-94 and Mars-96 projects are supported by many groups of scientists and engineers in different organizations both in Russia and the other countries participating in the project. Leaders of these organizations and groups – Academician Albert A. Galeev, Professor Vasily I. Moroz, corresponding member Vjacheslav M. Kovtunenko, Doctor Roald S. Kremnev, Doctor Vjacheslav M. Linkin, Doctor Yury A. Surkov and the principal investigators of the Mars-94/96 scientific instruments from scientific institutes and universities in Austria, Belgium, Bulgaria, the Czech Republic, Germany, Great Britain, Greece, Hungary, Finland, France, Ireland, Italy, Poland, Romania, Russia, Spain, Sweden, Switzerland, USA, and ESA – are the real authors of this paper.

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Discussion

H. Fechtig (*Max-Plank-Institute for Nuclear Physics, Heidelberg, F.R.G.*). Is the moveable platform available in time for the Mars-94 mission?

A. V. Zakharov. In my report I mentioned that a number of problems have been encountered in the preparation of the spacecraft and scientific instruments. Of the greatest concern are difficulties in the manufacturing and testing of the penetrators and a three-axis platform for the Argus complex (HRSC, WAOSS and OMEGA instruments). Both are behind schedule now. The technical director for the Mars-94 project submitted a new and highly strenuous schedule at the last International Scientific Council meeting. If every participant in the project completes the Earth-based testing of the spacecraft and its payload on time, the Mars-94 mission may be launched at the end of October 1994.

Note added in proof (4 November 1994)

In October 1994, it was decided to postpone the launch of the Mars-94 and Mars-96 missions by two years apiece. The projects have been renamed Mars-96 and Mars-98, respectively. To solve the weight problem ('payload mass deficit') caused by changing the ballistics for the Mars-96 flight path, it was decided to reduce the fuel needed for orbit modification. This means that the parameters given in this paper for the initial and working orbits of the Mars-96 orbiter will have to be changed.

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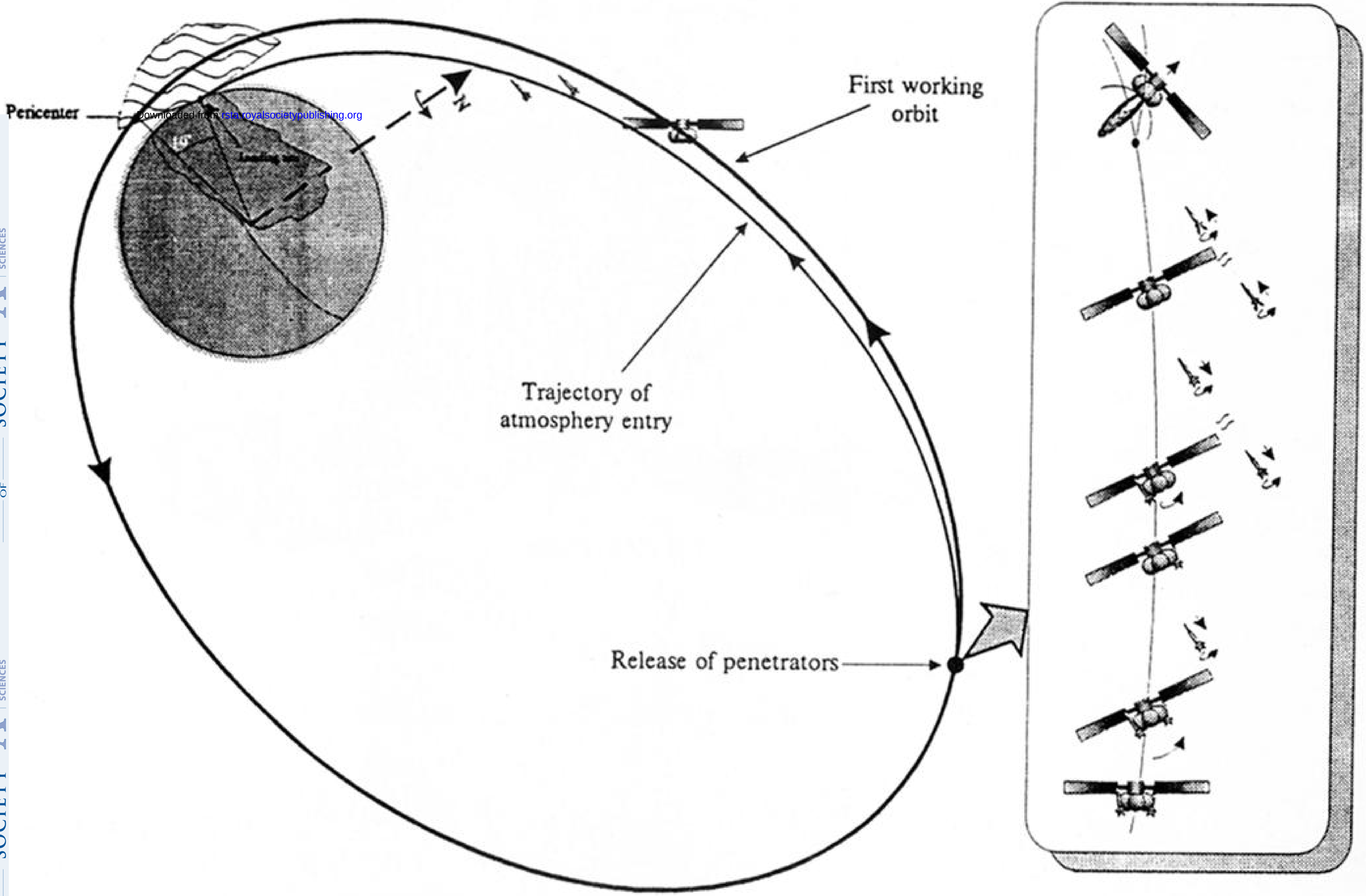

Figure 3. The descent of the penetrators.

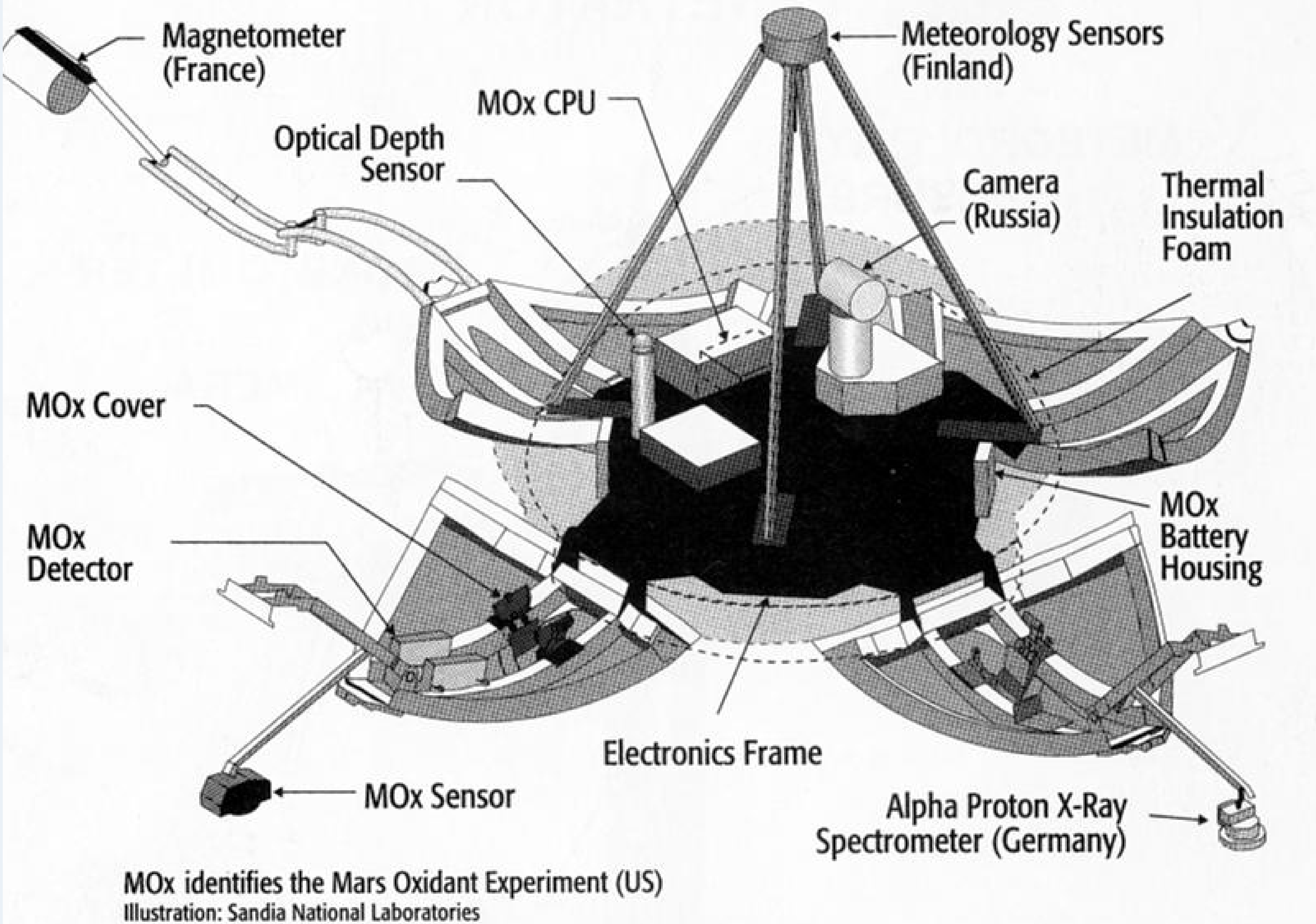

Figure 5. The small station configuration.

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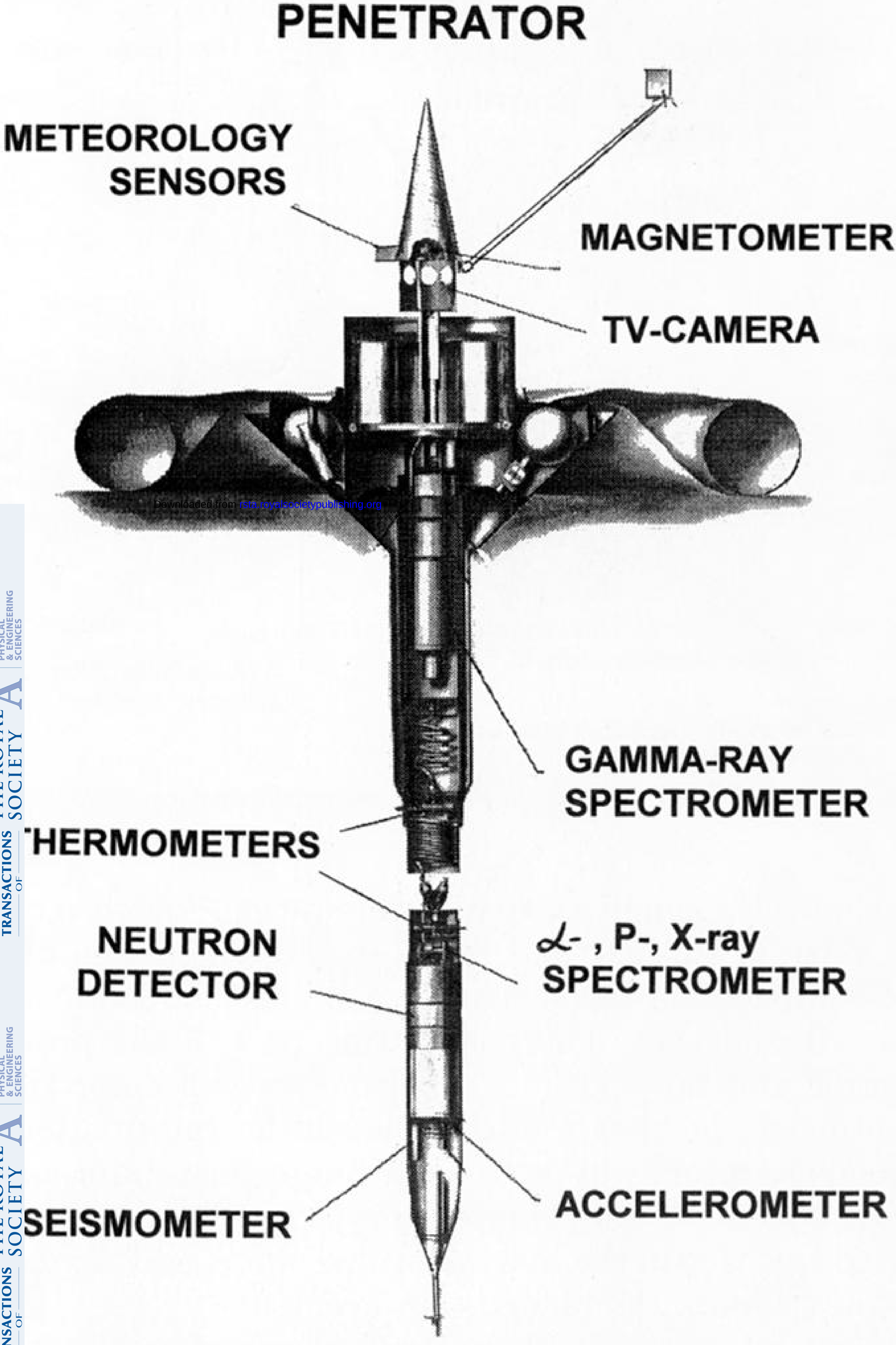

Figure 6. A section of the penetrator.

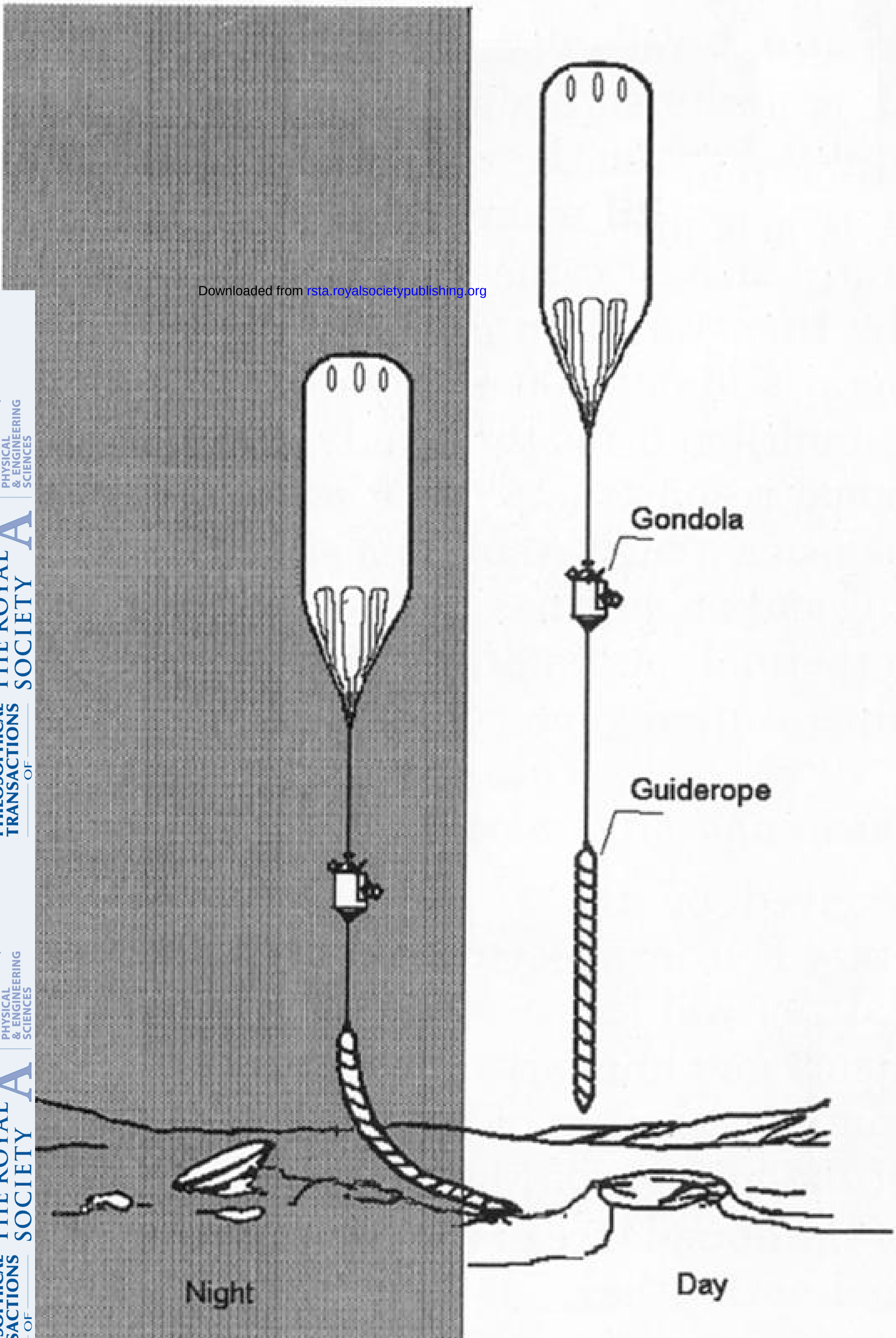

Figure 7. The operation of the balloon.

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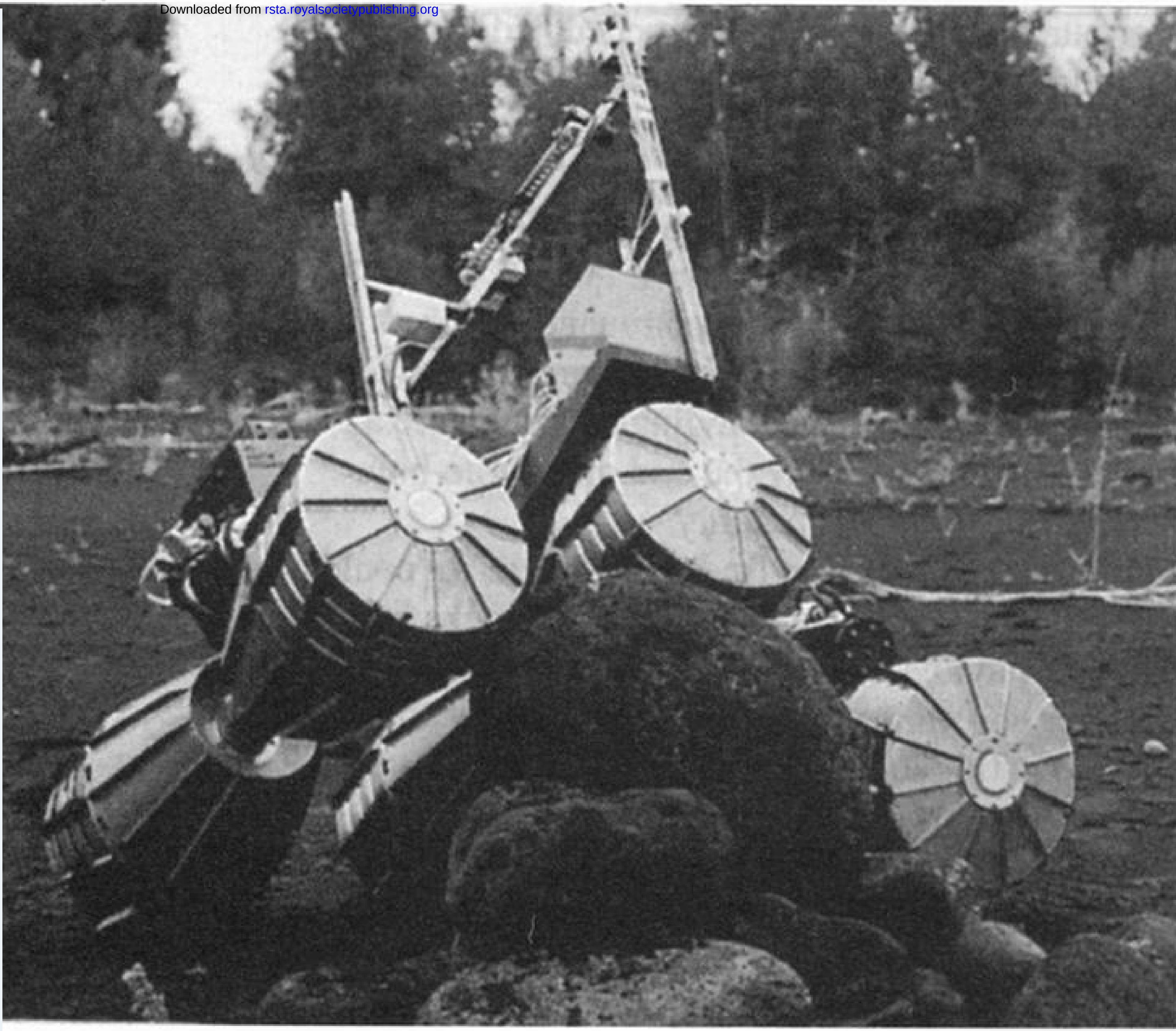

Figure 8. The Mars rover prototype.