4.2.1 Mission to Mercury

Introduction

Mercury is a planet of significant interest on more than one count. It is the innermost planetary member of the solar system and its average normalised density is much larger than that of any other terrestrial planet. Contrary to expectation, Mercury was found to have an intrinsic magnetic field, which has set severe constraints on planetary dynamo theory. Its Moon-like surface can reach up to 630 K, yet radar observations from Earth have revealed that water ice may be present in permanently shadowed craters near the poles. Its atmosphere is so thin that the planet surface forms the base of the exosphere. Its magnetosphere is also unique – the only one known without a significant ionosphere.

The observation of Mercury with Earth-based or Earth-orbiting telescopes is seriously hampered by the planet's proximity to the Sun. Our limited knowledge is partly based on three flybys of NASA's Mariner 10 probe more than two decades ago. A proposal for a mission to Mercury, with planetary and magnetospheric objectives, was therefore submitted to the European Space Agency in 1993. The design that emerged from an initial assessment study, in 1994, centred on a spin-stabilised orbiter relying on chemical propulsion and gravity assists from Venus and Mercury. Following the preliminary and promising results of this first study, the mission was identified as a cornerstone of the Agency's scientific programme, thus offering the prospect of a drastically different concept with a much more ambitious technical and scientific scope.

Scientific aims

Planetology objectives

The size and physical state of Mercury's core can be derived from the principal moments of inertia and rotational features, such as precession, nutation and libration. This will answer many open questions regarding the planet's density ($5.3\ \mathrm{g\ cm^{-3}}$, compared to $4\ \mathrm{g\ cm^{-3}}$ for Earth, normalised at a pressure of 1 atmosphere), the existence of a molten shell and the origin of the magnetic field. The observation of the topography and the gravity field will address issues related to the crust's evolution and reveal impact-induced features (mascons and basins).

Measuring the surface's elemental and mineralogical composition will contribute to the evaluation of the conditions that prevailed in the solar nebula during Mercury's accretion and formation. Global imaging over a wide spectral range is necessary for studying the planet's geological history and assessing the relative importance of endogenic and exogenic processes (seismic and volcanic activities, meteoroid bombardment) during Mercury's evolution and resurfacing.

Particles and fields objectives

Mercury's magnetic moment is relatively small (the equatorial field is about two orders of magnitude smaller than Earth's), but its importance is two-fold because it addresses both the internal structure and the interaction with the solar wind. It is therefore necessary to determine the dipole, quadrupole and higher terms of the planetary magnetic field and to survey their dependence on the current systems induced by the solar wind.

The planet's gaseous environment is best described as an exosphere. Production mechanisms are associated with the impact of photons, ions and micrometeorites; the exospheric composition therefore reflects that of the surface. The existence of five elements (O, H, He, Na, K) has been established, but it is highly probable that the possible presence of ice near the poles could contribute further volatiles.

The size of the hermean magnetosphere is only about 5% of Earth's, although the planetary radii differ by less than a factor of 3. The difference in scale sizes and the absence of an ionosphere at Mercury leads to differences in the dynamics of the two

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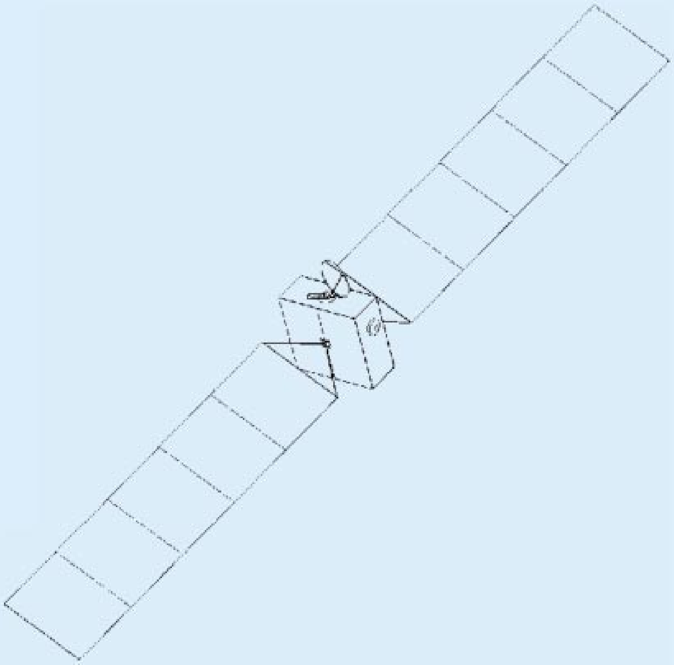
For further information on the mission to Mercury, see http://www.estec.esa.nl/spdwww/future/html/mercury.htm



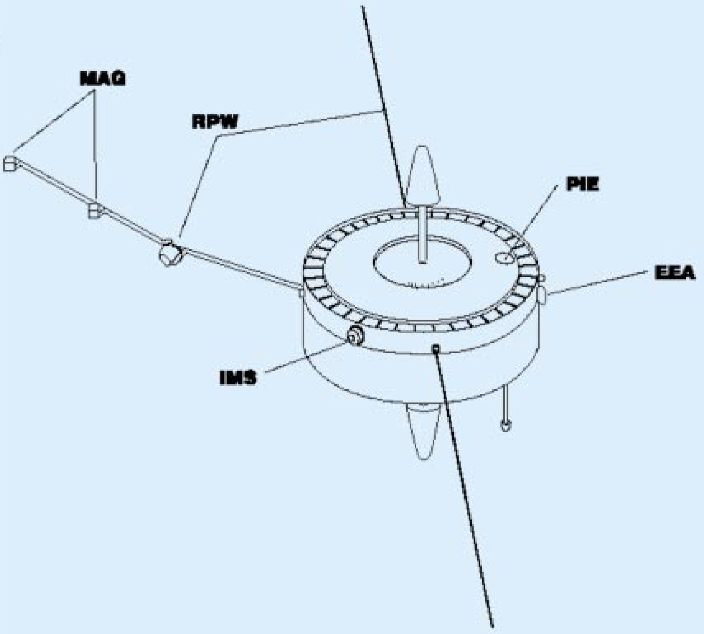


Figure 4.2.1.1 (left). The main Mercury spacecraft.

Figure 4.2.1.2 (right). The Mercury subsatellite. See Table 4.2.1.2 for explanations of the instrument acronyms.

magnetospheres and poses an important problem about the closure of the current systems that are needed to sustain the shape of the hermean magnetosphere.

Fundamental physics objectives

The Sun's proximity, the high eccentricity of Mercury's orbit and frequent solar occultations offer an opportunity for testing general relativity with improved accuracy and for performing new experiments based upon various observable quantities. These experiments rely on precision Doppler and ranging measurements and have to be considered as unique to this mission. The parameters quantifying the degree of nonlinearity in the superposition law for gravity, the parameter associated with the space curvature produced by mass, the time variations of the gravitational parameter G, and the J2 quadrupole moment of the Sun can all be measured with unprecedented accuracies.

Orbits

Electric propulsion is assumed to be available because it is more flexible for the choice of orbit and it imposes no launch window constraint because gravity assist is not required. The spacecraft is captured by Mercury into a polar orbit. Magnetospheric science prefers an elliptical orbit with periherm and apherm altitudes of 400 km and 16 800 km, respectively. For planetary science and radio science (gravimetry and relativity), a circular orbit at an altitude of 300-400 km is preferred, if this is compatible with thermal constraints.

There is, therefore, a need for either two mission phases or for two spacecraft. The second approach is being pursued because it also satisfies the cleanliness requirements imposed by the field and particle instruments. These are affected by the electromagnetic and chemical pollution from the electric propulsion system and are better accommodated on a small, electromagnetically-clean, subsatellite.

Table 4.2.1.1 Main orbiter instrument capabilities and requirements.

Instrument	*Acronym*	*Range*	*Mass (kg)*	*Average power (W)*	*Average TM rate (kbit/s)*	*Max. detector temp. (°C)*
Camera	CAM	350-1000 nm	8	10	7.4	- 53
IR spectrometer	IMS	800-2800 µm	6	10	1.5	- 27
UV spectrometer[1]	ALI	70-205 nm	2.5	3	2	+50
Gamma-ray spectrometer[2]	MGS	0.1-8 MeV	3	2	0.05	- 153
X-ray spectrometer[3]	MXS	0.5-10 keV	3	5	0.1	+20
Neutron spectrometer	MNS	0-5 MeV	5	3	0.05	+50
Solar monitor[4]	SOM	-	1	-	-	-
Radio science[5]	RAD	-	-	-	-	-
		Total	**28.5**	**33**	**11.1**	**(6)**

1: Tiltable mirror not included. 2: Germanium detector. 3: Solid-state detector. 4: Pointing facility not included. 5: Mostly based on existing up/downlink TM facility.
6: Cooling system required.

Table 4.2.1.2 Subsatellite instrument capabilities and requirements.

Instrument	*Acronym*	*Ranges*	*Mass (kg)*	*Average power (W)*	*Average TM rate (kbit/s)*	*Max. sensor temp. (°C)*
Magnetometer	MAG	±64/±256/±1024/±4096 nT	2.5	2.5	1	+150
Ion spectrometer	IMS	10 eV-30 keV, 1-100 amu	7	5	1	+30
Electron analyser	EEA	5 eV-30 keV	2.2	2.5	1	+40
Wave receiver	RPW	0.1 Hz - 16 MHz (electric) 0.1 Hz - 1 MHz (magnetic)	6.6	6	1	+170
Ion emitter	PIE	1-100 mA	2.7	3.8	0.020	+100
		Total	**21**	**19.8**	**4.020**	**-**

Satellite and instruments

The instruments devoted to planetary studies are mounted on the main spacecraft (Figure 4.2.1.1) and point along the nadir during scientific operations. Imaging and spectral analysis are performed in the IR, visible and UV ranges. Gamma-ray, X-ray and neutron spectrometers yield additional data about the elemental composition of the surface material (Table 4.2.1.1).

The fields and particles instruments are accommodated on a subsatellite, spin-stabilised to facilitate the deployment of a wire antenna and the azimuthal scan of the sensors (Figure 4.2.1.2). A dual 3-axis magnetometer and search coils are mounted on a deployable boom. Plasma investigations are supported with an ion spectrometer and an electron analyser. An ion emitter controls the spacecraft potential (Table 4.2.1.2).

It is estimated that the solar array should deliver 20.5 kW, including 18 kW for electric propulsion. The total mass is of the order of 3.7 t, including 1 t of propellant (xenon). The spacecraft is launched by Ariane 5 in 2009, at the earliest, and reaches Mercury after an interplanetary transit of 700-1000 days, depending upon thrust (1-1.7 N). A system and technology study is being conducted by an industrial consortium with the aim of defining system trade-offs, investigating a number of critical areas and providing an estimate of the mission cost.

Science operation

One possible mission scenario is the following:

1. The spacecraft complex is captured into a polar orbit with a radius of 6 R_M (1 R_M= 2440 km). Preliminary radio science and low resolution mapping are carried out.
2. The apoapsis altitude is kept constant and the periapsis altitude is lowered to 300 km.
3. The subsatellite is released.
4. A lander or a penetrator is also released, if such an operation is feasible.
5. The orbit of the mother spacecraft remains polar and is circularised with a radius of 1.5 R_M.
6. Global low-resolution mapping of the planet is performed during a period of about 176 days.
7. The altitude of the spacecraft is lowered to 300-400 km, if this is compatible with thermal constrains.
8. High-resolution observations of the surface are performed over selected areas.
9. The radius of the orbit is raised again to 1.5 R_M, but with a different phase at Mercury periapsis.
10. Additional low-resolution mapping is completed.

During the entire mission, the mother spacecraft acts as a relay for the subsatellite and, possibly, the lander.