The Mercury MESSENGER

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FUTURE MERCURY ORBITER CONSIDERED

A Report from the 1995 ESA-Sponsored Mercury Study Workshop

On May 22–24 of this year, the European Space Agency sponsored a Mercury study workshop, which was hosted by the Space Physics Group at Imperial College in London. The purpose of the workshop was to further develop the concept for the Mercury mission planned by the European Space Agency as part of its 2000 Plus series. Also discussed were the state of our current understanding of the planet and instruments currently available or under development that could be flown on such a mission. A special issue of the journal *Planetary and Space Science*, entitled *Mercury and Its Magnetosphere*, will consist of papers submitted by participants in this workshop and will be published sometime next year.

During the first day of the workshop, reviews of our current state of knowledge of Mercury's interior, surface, exosphere, and magnetosphere were presented. In addition, a presentation was given on the compositional information (considered the greatest "missing link" in our understanding of Mercury and therefore a most essential component of the mission) that could be provided by X-ray and γ ray spectrometers. On the second day, detailed presentations on our present understanding of Mercury were given. Presentations on the planet's interior structure, external structure, and volcano-tectonic history were followed by presentations on its magnetosphere and exosphere. On the third day, the most significant unanswered questions were developed into mission goals by rapporteurs, and details of the mission plan were presented.

Overview of Proposed Mission

The European Space Agency recently proposed a Mercury Orbiter (see Fig. 1) as a major mission for their Horizon 2000 Plus (post-2000 launch) program. This mission is now being considered for the number five position in the present ESA launch queue, following the Rosetta (comet encounter) mission—not a great position for a Mercury mission, but better than not being in a launch queue at all. According to calculations done by Chen Wan Yen, a launch opportunity in 2004 is most favorable; 2007 is presently under consideration. Few opportunities exist after the year 2007. Since the mission would have a cruise phase of 3–4 years, the earliest arrival possible would be 2008.

The proposed mission is designed to include instruments that would provide measurements relevant to a wide range of disciplines, including planetary (surface) and exospheric sciences, as well as solar, magnetospheric, and fundamental physics. Eight instruments are included in the 50-kg strawman payload, including a multispectral imager, X-ray spectrometer, γ ray spectrometer, magnetometer, ion spectrometer, electron analyzer, wave analyzer, and ion gun. The total power requirement is estimated to be 50 W. Two booms would be required for the magnetometer and plasma wave instrument. The telemetry rate would be 2–9 kbits/s during the encounter depending on the Earth distance, and less than 2 kbits/s during cruise.

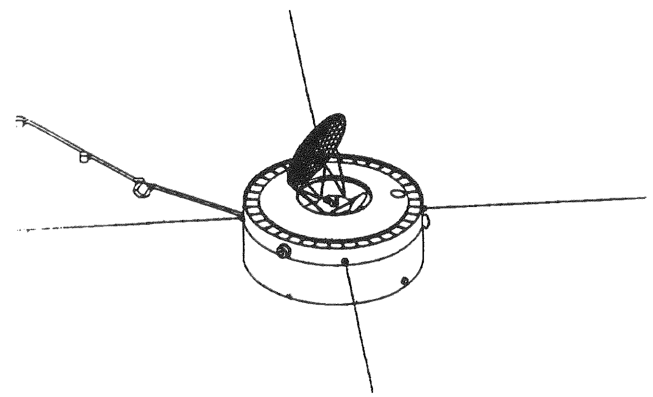

Fig. 1. Mercury Orbiter spacecraft configuration.

The 50-kg payload, which has a 250-kg margin at this point, would be flown on a spin-stabilized spacecraft that would require an Ariane 5 launch. Because of this large margin, an additional geophysical subsatellite, penetrator, or atmospheric probe is being considered; also under consideration is the addition of a UV spectrometer or stereoscopic solar imager to the orbital payload. The DSN would be required for tracking. Upon arrival, the spacecraft would be placed in a near-polar orbit, with spacecraft spin axis nearly parallel to the planetary spin axis. (The spin axis will be tilted a couple of degrees closer to the Sun than the planetary axis to get more power.) Periapsis will be approximately 400 km at 45°N latitude, and apoapsis approximately 16,000 km at 45°S latitude (see Fig. 2). Periapsis would not correspond to the surface subsolar point until aphelion. Measurements would be taken from this orbit for at least one year. The result of this flight trajectory would be that most of the surface coverage would be in the northern hemisphere, with little coverage in the south.

Special spacecraft designs are necessitated by the high heat flux in the Mercury environment. The spacecraft will be provided with a well-insulated (kapton-coated) body, as well as louvers and electrical heaters to minimize heat fluctuations. The spacecraft core will be designed with conductive coupling for high thermal inertia. Some instruments will require Peltier coolers.

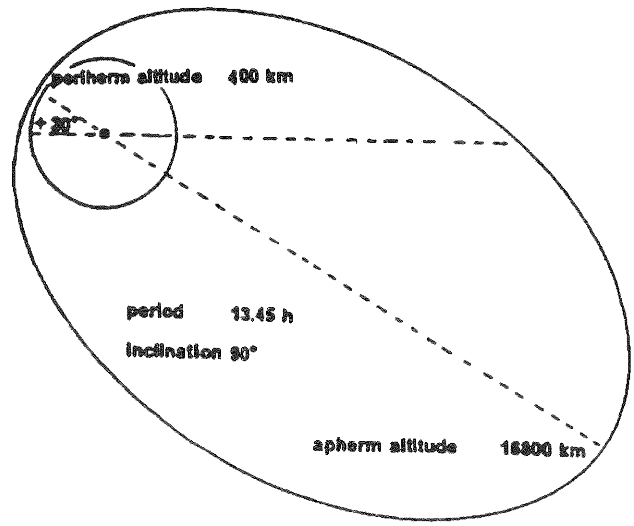

Fig. 2. Mercury Orbiter operational orbit.

Also presented was a proposal for an electric-propulsion Mercury Orbiter and Lander mission that had a shorter cruise time of about two and a half years and had a proton launch, and thus could carry a comparable orbital bus as well as a lander with a couple of instruments. A 1000-km, nearly circular orbit was proposed. The thermal problems connected with instruments on nadir-pointing spacecraft could be considerable, even at 1000 km (see Issue 4 of this newsletter). An advantage of this design was the high available onboard power of 25 kW.

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Science Reviews and Objectives

One workshop attendee, Jim Slavin, summed up the viewpoint of many of us quite well in two statements: "The exploration of the planets will not leave its initial stage until the basic properties of the inner planets have been surveyed," and "I can't think of a better place to go and ask questions than the planet Mercury." Thus, a Mercury orbiter mission would be the next logical step in the exploration of the solar system. Considered here are the discussions of major questions left unasked and experiments proposed to answer them in each discipline.

Magnetospheric/Heliospheric Science (Rapporteur: J. Slavin)

Before Mariner 10, the consensus was that Mercury would not have a magnetic field. In the preliminary analysis of the data from the first flyby, magnetometer data indicated small magnetic field variations that were interpreted to be solar wind induced and not intrinsic. Upon further study and after receipt of the data closer to the planet from the final flyby, it became clear that Mercury's magnetic field is very much like the Earth's, a dipole requiring an internal dynamo and implying extensive differentiation and a partially molten Fe-rich inner core. On the other hand, Mercury has neither radiation belts nor an ionosphere. The

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Hermean magnetosphere may provide the best laboratory in the solar system for testing and extending the lessons learned from Solar Terrestrial Science Program (STSP) missions in the Earth's magnetosphere. (A future issue of this newsletter will describe Mercury's importance to magnetospheric research in more detail.)

The goals of magnetospheric and heliospheric physics investigations would be similar to those proposed in the NASA Space Physics Mercury Orbiter working group study (see Issue 4 of this newsletter). The topics that should be addressed by the proposed mission include the following:

- In solar physics, investigations of the neutron, X-ray, gamma ray, and energetic particle fluxes produced by nuclear processes in solar flares.
- In heliospheric physics, the dynamics of solar wind streams and shocks as well as the acceleration and transport of solar cosmic rays.
- In magnetospheric particle physics, investigations of magnetic fields, plasma composition, plasma waves, substorm dynamics, energetic particle acceleration, and regolith/magnetosphere coupling (which also has implications in exospheric studies, see below).
- Planetary magnetic studies will include mapping of the global magnetic field, and determining the relationship of magnetic anomalies to observed variation in chemical composition or gravity.

Atmosphere/Exosphere and Surface Interactions

About a decade ago, the Na and K exosphere of Mercury was discovered by Potter and Morgan. (An atmosphere with less than 10^{13} cm^{2} column density is called an exosphere.) A Na and K exosphere has now been described for the Moon as well. (A future issue of this newsletter will describe the work on the mercurian exosphere in detail.) Potassium emission is 1% of the observed Na emission, so Na emission is much easier to measure. Work that needs to be done in this area involves understanding the exosphere production and the important surface/exosphere/magnetosphere coupling mechanisms. In addition, because recent radar observations of Mercury appear to indicate the presence of ice near the poles, Killen suggested that a UV spectrometer could be flown on this mission to measure not only Na and K, but also OH, to determine if ice was indeed present near the poles.

Other types of investigations that might be considered were suggested by Grande and Lundin, including imaging of neutral particles, as opposed to ions, sputtered from surface, and imaging X-ray emission from auroras, the output of which might be comparable to the solar flux. These observations would require X-ray and UV imaging devices.

The UV experiment proposed by these investigators, and described in detail by Morgan, requires a new far-UV detector that is thermal over a large range, and is quite modest in weight (2 kg) and power (3 W) requirements. Such a spectrometer could easily be added to the proposed payload without compromising weight and power constraints. Wedge and strip detectors get longitude, latitude, and UV intensity as separate outputs. The instrument is primarily designed to do exospheric measurements, down to the He line, with high sensitivity; however, this experiment can do surface measurements with an occultation port at kilometer-scale resolution as well, and these investigators believe that a good UV spectrum of the planet, including an Fe line in the UV region, is crucial. So far, investigators are uncertain about how to deal with all ions. A number of magnetospheric science investigators consider such a UV spectrometer to be extremely useful in understanding "space weather," as indicated above.

TABLE 1. Official strawman payload.

Instrument	Mass (kg)	Power (W)	Characteristics
Multispectral Imager	9	10	Range: 200–1100 nm Spectral resolution: 250 nm Spatial resolution: 20–80 m/pixel @400 km
Magnetometer	3	3	Ranges: ±64, 256, 1024, 4096 nT
X-Ray Spectrometer	5	4	Range: 0.7–8 keV Spectral resolution: 15–30% Spatial resolution: 30–50 km
Gamma Ray Spectrometer	10	8	Range: 0.1–8 MeV Spectral resolution: 4–8%
Ion Spectrometer	7	5	E/q range: 10 eV–30 keV, M/q range: 1–100 amu Spectral resolution: 1–10%
Electron Analyzer	2	3	Range: 5 eV–30 keV Spectral resolution: 8%
Wave Analyzer	11	7	Range (Electric field): 0–16 MHz Range (magnetic field): 0.1 Hz–1 MHz
Ion Gun	3	4	Range: 10–100 uA Spectral resolution: 0.2 uA
Total	50	44	

Hard Stuff: Surface, Interior Structure, and Shape (Rapporteur: Y. Langevin)

Investigations of most interest in this disciplinary area involve understanding the surface and interior chemistry, geological history, and morphology. The information totally missing from this picture is direct compositional measurements of any kind, which are of utmost importance. Although a large Fe/Si ratio in the planet as a whole is implied by the presence of a planetary dipole magnetic field, which requires a dynamo, global composition has yet to be determined. Morphology and geological mapping alone will not provide a model for the history of Mercury's crust and mantle. The existence of one large impact basin, Caloris, and radar profiles that indicate highly variable topography in the unimaged hemisphere may indicate extensive early bombardment and a possible global asymmetry, as on the Moon. Volcanic activity is certainly indicated, but on a scale that is still highly uncertain.

What is known about Mercury is that it has a fine-grained regolith probably similar, though not identical, to the Moon's. If this is the case, then the regolith could be characterized as "mature," with about 50% glass content. This information is based on measurements made by the radiometer on the Mariner 10 flyby. Recent observations have indicated that ice deposits exist in craters near the poles. Further characterization of the regolith, as to thickness and temperature, would require a radiometer, which is not part of the payload proposed here, and not considered to be of the highest priority. Regolith "maturity," where a darkening effect occurs, is generally considered to be the result of solar wind sputtering. How does this process affect the exosphere composition? If it does, a correlation between surface and exosphere composition should exist, and could be measured.

Recommendations for planetology instruments and investigations are as follows:

- X-ray and γ ray spectrometers, along with an imaging spectrometer, would be the highest priority instruments here. An X-ray spectrometer could provide maps of Mg, Al, Si, Ca, Fe, and possibly Ti composition on scales of tens of kilometers; a complimentary γ ray spectrometer could provide maps of Th and K radioactivity, as well as Fe and Ti on a larger scale but down to greater depth.
- The location and width of the "Fe band" in spectral reflectivity and UV data may indicate the degree to which Fe is reduced in Mercury's crust, and thus resolve questions about the planet's origin.
- A neutron detector, of lower priority here, would detect water ice, providing further proof that it does indeed exist near the poles.
- The combination of a high-resolution multispectral imager and an altimeter not mentioned in the strawman payload would be extremely useful in allowing accurate mapping of the many tectonic features, including scarps and grabens theoretically associated with major tectonic episodes in Mercury's history, as well as any global asymmetry.
- In order to better determine Mercury's figure, including its spin axis, ellipticity, and mass distribution, while improving ephemeris (tracking data) from that planet, DSN tracking, preferably with X- and S-band downlink transmitters, is required. DSN tracking was discussed at this meeting, but is not considered in the formal proposed mission document at this point.
- If weight and power constraints can be met, inclusion of one or more of the following instruments should be considered: an IR spectrometer, neutron detector, UV spectrometer and/or laser altimeter, and a higher-resolution (10 m or less) multispectral imager, for reasons mentioned above. The big bottleneck here would be obtaining data rates and meeting weight and power requirements for a high-resolution imaging spectrometer, an unresolved issue.

Organizational Information

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