HERMES GLOBAL ORBITER

A Discovery Mission in Gestation

by

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1. INTROD[JCTION

The Hermes Global Orbiter (HGO) is a Discovery class mission under study, which is investigating the possibility of placing a small spacecraft in highly elliptical polar orbit about Mercury. The purpose of the mission is to conduct observations of the planet's surface, atmosphere and magnetosphere. The prospective mission calls for the spacecraft to be in Mercury orbit for one Earth year.

The payload contains four subsystems: a multispectral imaging camera, an ultraviolet spectrometer, a lidar, and a magnetic field and plasma experiment. The first three subsystems are mount ccl on a single axis scan platform and the magnetic field and plasma experiment is boom deployed.

This payload is capable of making observations that address a number of fundamental questions about Mercury and its role as the planet which condensed in the hottest region of the solar nebula. The Hermes mission seeks to understand Mercury 's surface, its tenuous atmosphere, and interior structure. The proposed investigation will provide important insights into the probable composition, interior structure and thermodynamics of the hot inner portion of the protoplanetary accretion disk. The results of this mission, particularly when contrasted with the results of missions to the outer planets, will lead to significant advances in understanding the process of solar system formation and planetary evolution for objects which condensed in dissimilar environments.

The Hermes launch strategy employs a NASA provided Delta 11 launch vehicle. given this constraint, the energy limitations require an interplanetary transfer that involves multiple flybys of Venus and Mercury prior to Mercury Orbit Insertion (MO]) to pump the heliocentric orbit down to the desired Mercury orbit. The Hermes instruments will be taking data during the Mercury flybys to ensure that a flyby quality data set is obtained as a minimal goal in the unlikely event of an unsuccessful orbit insertion activity.

The HGO is being planned for a 1999 launch opportunity and it would require a new NASA start in FY'96. The interplanetary transfer is 3.3 Earth years. The orbital mission duration is one Earth year. The mapping orbit at Mercury will be a 200 km periherm by 12 hr orbit period (about 15,000 km apoherm).

The spacecraft options under consideration utilize a great deal of heritage from prior spacecraft developments. The key elements are the TRW Lightsat being used for TOMS-EP as the baseline bus, the AB series bus for the propulsion module subsystem (1 'MS), the TRW dual mode liquid apogee engine (1,.41+;) for the PMS, TRW graphite fiber wrapped tanks for the PMS, the Cassini solid state recorder (SSR), the JPL/TRW

X-band solid state power amplifier (SSPA), TRW heat pipe technology and the TRW gallium arsenide solar array technology.

The project will be managed such that the $150M project cost cap to launch +30 days is maintained. The project will maintain a 30% contingency on the costs. The spacecraft will maintain a 30% contingency and a 30% launch vehicle mass margin through Phase A. The project would be managed at JPL under the direction of Robert M. Nelson, the principal investigator. The spacecraft and its associated system engineering would be provided by TRW. The mission design would be provided by JPL, as well as the mission operations concept. Product assurance during the hardware development will be provided jointly by TRW and JPL with TRW being the lead. The payload would be provided by university and industrial affiliates of the Hermes team.

2. SCIENTIFIC QUESTIONS UNDER CONSIDERATION

The goal of this mission is to understand Mercury's significance in planetary formation by (1) determining Mercury's surface topography, composition, texture, and mineralogy; (2) searching for condensates at Mercury's poles; and (3) constraining Mercury's interior structure.

The Mariner flyby mission in 1974 established that Mercury has a surface morphology which, to first order, approximates that of the Earth's moon. However, upon closer examination, Mercury is found to be quite distinct from the moon and other terrestrial planets. It has a tenuous atmosphere, an intrinsic magnetic field, and it has morphological structures which most probably arose from different processes from those which dominated the creation of the moon and Mars. Recent evidence suggests that water ice is present at the Hermean poles. The Hermes mission will investigate important questions that have been raised by the scientific community based on information learned from previous groundbased and spacebased observations. These include:

2,1 *What is the composition of Mercury's surface?*

There is virtually no information available about the composition of Mercury's crust. In particular, the ferrous bands of pyroxenes and olivines near 1 micron and 2 micron, which are so valuable in understanding the mineralogy of the lunar surface, have not been positively identified on Mercury. If the depth of these bands can be measured, an estimate of the iron content of the assumed regolith can be made. Part of the problem is that Mercury appears to have a low-Fe crust, so that these bands are intrinsically weak. In addition, the planet's high temperature causes thermal emission to become important at wavelengths as low as 1.5 micron, filling in absorption bands and making it difficult to interpret this region of the infrared spectrum. However, ferrous iron in silicates also has a strong band at 0.26 micron. This band has not been studied from Earth-based observatories because of the ozone cutoff in the Earth's atmosphere, nor can it be observed with the Space Telescope or with IUE because of Mercury's proximity to the sun. However, this band would be easily observable by the instruments on HGO from Mercury orbit.

The HGO optical instruments can measure the abundance of iron in two ways. The camera will image the surface at several wavelengths in the wings and interior of the "1 micron band. However, since this band is a forbidden one, it may be too weak to detect if only small amounts of iron are present. By contrast, the 0.26 micron band is an allowed transition and should be observable by the UVS even if only trace amounts of iron are present. The depths of these bands will constrain the composition and mineralogy of the regolith.

2.2 *Is there ice at Mercury's poles?*

Regions near the poles of Mercury have anomalously large reflectivities and polarization ratios when observed at radar wavelengths. Because of the similarities of these radar properties to those of the surfaces of icy satellites, it has been suggested that Mercury may have polar caps of ice, presumably in permanently shadowed regions inside craters near the poles. Such regions would be undetected by a passive reflectance experiment because they would be unilluminated. However, they would be readily observable by the 11(;() active laser photopolarimeter experiment. This experiment measures the intensity of the spacecraft's laser light reflected from Mercury's darkside. A high reflectivity would be consistent with exposed water ice.

In addition, the UVS can also detect the presence of OH, a dissociation product of water ice. Measurement of the distribution of OH in the atmosphere can be used to determine erosion mechanisms (e. g., sublimation, sputtering, etc.) and transport in the atmosphere, which affect lifetime and evolution of potential ice deposits.

2.3 *What is the normal albedo and particle size distribution of Mercury's regolith?*

The Hermes active polarimetry experiment will measure absolute normal albedos of Mercury's surface features. The normal albedo is an important characteristic of a regolith and it contains information about its texture and composition. The laser photopolarimeter investigation will measure the circular polarization ratio of the light reflected from the surface. Laboratory experiments have shown that, for low albedo surfaces such as Mercury's regolith, the circular polarization ratio is small when the particles are large compared to the wavelength of the incident light. Thus, the relative number of wavelength-sized particles in an area can be constrained, mapped and related to the geological history.

2.4 *Are there expressions of volcanism on Mercury's surface and are the volcanic units representative of the Hermean interior?*

A major unresolved issue posed by the Mariner 10 data is whether Mercury's smooth plains were formed by flowing lava, impact ejecta, or a combination of both. High resolution imaging data can be used to look for diagnostic small-scale features such as lava channels and flow fronts. Compositional information will be derived from multifilter photometric data acquired by the imaging system.

If no evidence of past active volcanism is found from either the global imaging survey or from surface composition measurements, then Mercury's geologic history would be significantly different from that of the other terrestrial planets. However, if volcanic units are found, it will be possible to probe the nature of this activity over time, and the role of volcanism in the complex tectonic history of Mercury.

2.5 *What was the role of impact cratering in determining Mercury's surface morphology?*

Mercury has been significantly altered by major impact processes. The 1300 km-wide Caloris basin represents one of the most catastrophic impacts known on a terrestrial planet. Basin scale impacts significantly perturb the thermal state of the lithosphere and play a significant role in a planet's thermal history. Imaging data showing the whole of Caloris, together with detailed topographic data provided by the laser altimeter can be used in combination with models of viscous relaxation of topography to constrain fundamental properties of the interior, such as thermal gradient and crustal thickness.

2.6 *What is the relationship between the surface topography and the interior structure of Mercury?*

The laser altimetry experiment combined with radio science information from the spacecraft's down link transmitter can be used to derive simultaneous topography and gravity field models to produce a global geodetic control grid map of Mercury. The relationship between the topography and the gravity field can be used to study the internal structure and dynamics of the planet and the mechanism of isostatic rebound.

2.7 *What is the composition, evolution and dynamics of Mercury's atmosphere?*

Mercury's tenuous atmosphere is a surface-boundary exosphere. The atmospheric composition and behavior are controlled by its interactions with the magnetosphere and surface. A number of mechanisms for generating various atmospheric species including surface sputtering, solar wind capture, and photodissociation are likely. Meteoric infall and internal outgassing are also possible mechanisms. Loss mechanisms such as photoionization (with subsequent escape along magnetic field lines) balance the production mechanisms to establish equilibrium. Both production and loss rates are certainly variable due to changing heliocentric distance, variations in solar UV output and changes in heliocentric radial velocity. Spectroscopic studies of known species and the discovery of yet undetected species at both ultraviolet and visible wavelengths can be used to establish priorities among the various competing mechanisms, and lead to a more complete understanding of the composition of Mercury's surface.

2.8 *What is the nature of Mercury's interior and what is its relationship to the spatial and temporal variations of the Hermean magnetic field?*

The Mariner 10 spacecraft detected an intrinsic magnetic field at Mercury that extends 1,5 to 2 Mercury radii above the surface. Mercury is believed to have a large metallic core surrounded by a relatively thin liquid shell. The dipole moment of the field is only known within a factor of two and the quadrupole and higher order moments are completely unknown. Mercury's magnetosphere is only about 0.05 the size of the Earth's magnetosphere. The Hermes magnetometer will measure the magnetic field of Mercury, its magnetosphere, and its interaction with the heliosphere. Understanding the magnetic field will provide important information about the nature of Mercury's interior. In addition, HGO will have ample opportunity to observe a variety of important interactions between the magnetosphere and the solar wind. The small size of Mercury's magnetosphere will allow the spacecraft to completely traverse it in less than 30 minutes, providing important spatial and temporal information under constant solar wind conditions.

3. SPECIFIC OBJECTIVES

The principal experimental objectives of the Hermes mission are to:

1. Obtain a complete map of Mercury's surface at 1 km resolution with a significant portion (40%) of the surface mapped at 0.1 km resolution.
2. Determine or constrain the nature of the principal mineralogical species on Mercury's surface utilizing multispectral imaging. In particular, test for the presence of water ice on the surface.
3. Determine the physical state of the Hermean regolith.

4. Map the planet's gravitational field.
5, Map the planet's magnetic field.
6. Determine the distribution and temporal behavior of Mercury 's known atmosphere.
7. Search for yet undetected atmospheric constituents.
8. Study the interaction of' the magnetospheric plasma wit 1 the atmosphere and surface.

4. MISSION DESIGN AND ANALYSIS

The 1 IGO mission design focuses on: (1) design of heliocentric trajectories required to get the spacecraft to Mercury, (2) design of an end-to-end mission scenario that satisfies the basic science requirements while constraining costs, (3) design of a Mercury phase orbital sequence, and (4) the assessment of performance.

This mission is best described in two major mission phases, the heliocentric transfer phase and the Mercury orbiting phase. The spacecraft will spend about four Mercury years (352 Earth days) in order to carry out well coordinated experiments through various mission phases.

The mission will begin with the launch of the spacecraft from a Delta II which will place a three axis stabilized spacecraft into a heliocentric transfer orbit. Our design focused on a July, 30, 1999 launch date as the primary launch opportunity.

The basic concept of the heliocentric trajectory design is based on multiple gravity assists of Venus and Mercury. To arrive at Mercury with a sufficiently low Vinf for low DV orbit capture, the spacecraft will undergo two Venus swingbys and two Mercury gravity assists. It will take three Earth years of transit time. For the 1999 mission, two Venus and two Mercury swingbys are made and MOI is made on the third Mercury encounter. This sequence takes about 3.3 Earth years to execute and is designated as EV2M3.

The first Venus flyby helps to lower the Earth departure C3 requirement and orients the spacecraft orbit plane into the plane occupied by Mercury. With the second flyby of Venus, the perihelion of the orbit is lowered to about ().3 AU, where Mercury's orbit is located.

The Mercury gravity assists, combined with deep space maneuvers between the flybys, serve to lower the aphelion of the transfer orbit towards that of Mercury's orbit. Since there is a limit as to how much lowering one can obtain with a single planetary fly by, more than one Mercury flyby is employed in the trajectory design. Each Mercury flyby successively contributes to the desirable goal of a low Vinf at Mercury.

A schematic of the interplanetary transfer for the 1999 launch opportunity is shown in the figures that accompany the paper by Yen, Wallis and Horn (this meeting). These schematics show the encounter periods.

The design of the Mercury orbiting phase is structured to meet the science requirements with a minimum possible expenditure of propellant. Most of the orbit designs were driven by: (1) the desires of the magnetosphere investigators to achieve comprehensive coverage of the magnetosphere at' Mercury, and (2) the desires of the planetology investigators for good c.overage and resolution of the planet's surface.

The orbit chosen is a 200 km X 12 hr (apoherm of about 15, ()()() km) polar orbit. The periherm is near the equator. The MOI will be on the dark side of the planet and will last approximately 23 minutes.

The choice of the orbit size at Mercury is also dependent on the mapping image resolution requirements. '1'0 obtain image resolution on the order of 100 m, the mapping altitude will have to be about 1000 km. It is then desirable that the orbit be circular to obtain a uniform global mapping at the 100 m resolution and a nadir pointing spacecraft. However, a circular orbit about Mercury places the spacecraft in an unmanageable thermal environment and therefore an elliptical orbit has been selected. The DV difference between a stable 200" km X 12 hr orbit and a 200 km circular orbit is on the order of 1.0 km/s. Also, since it is not known what mas cons or gravity anomalies may be present at Mercury, a low polar orbit may require significant orbit sustenance DV as opposed to a high elliptical orbit requiring none. From this prospective, the choice was a 200 km X 12 hr polar orbit. This would produce image resolution on the order of 100 m over ~40% of the planet near the equator with lower resolution over the polar regions.

Because it is assumed that the J2 of Mercury is nearly zero, the orbit will not precess, but remain inertial. At the periherm altitude, the spacecraft will move from full solar illumination to total darkness over half of a Mercury year (1 Mercury year= 88 Earth days). It will also experience two sunrises and sunsets twice in Mercury year. The spacecraft will see maximum eclipse periods of about 120 minutes.

5. SPACECRAFT DESIGN CONCEPT

The spacecraft uses a great deal of heritage from prior TRW spacecraft developments. The key elements are the Lightsat test bed being used for TOMS-EP, the AB600 bus, the TRW dual mode LAE for the PMS, TRW graphite fiber wrapped tanks for the PMS, the SSR, the JPL/TRW X-band SSPA, TRW variable conductance heat pipe (VCHP) technology and gallium arsenide solar array technology.

The main bus strut.tum would be the AB600. This module would contain most of the electronics and payload. The TOMS-EP avionics will be baselined. It would be surrounded by the propulsion system tanks and pressurant bottles which are supported by a truss structure tied into the core module. These modules in turn will be insulated by MLI blankets.

The dual mode propulsion system was sized for nominally a two to three year interplanetary transfer. The main engines would be two 560 nt motors (used in a bipropellant mode). The attitude control engines would be used in a nonpropellant mode with thrust levels on the order of 22.5 nt. The baseline attitude control sensors for either spacecraft would include star scanners and sun sensors.

With a 40 kbps data rate requirement and a 12 watt RF power X-band solid state power amplifier, the spacecraft will require about a total of 255 watts of electrical power. This would include about 50 watts of power for the payload and 203 watts for the remainder of the spacecraft. Solar arrays would provide this electrical power. These arrays would have gallium arsenide solar cells. Also, these arrays on this three axis stabilized spacecraft would be articulated about a single axis to optimize the thermal input and electrical power output required throughout the mission. The batteries required would be about 15 Ah with about a 55% depth of discharge during the orbital mission. The spacecraft allows for the solar array to be oriented on edge when in the subsolar point in the orbit and receiving both the solar input and the infrared input from the planet.

The spacecraft heritage would be off the shelf spacecraft parts. This spacecraft would be configured to operate at Mercury for a one year orbital period with a total mission duration of about 5 Earth years inclusive of the 3.3 Earth years in transit to Mercury. A detailed description of the spacecraft options under consideration during this study is found in Cruz and Bell (this meeting).

6. HERMES SCIENCE PAYLOAD

The Hermes science payload consists of the visible light imaging system, the laser altimeter, the ultraviolet spectrometer, and magnetometer/plasma sensor. Except for the magnetometer, all the instruments are mounted on a scan platform which will be single or two axis depending on a more detailed set of integrated observation requirements which will be determined downstream. The magnetometer/plasma subsystem is 1)00111 mounted at about 2 to 3 lengths of the maximum spacecraft dimension.

Total volume of the science payload is about 200 liters. The telescope and lidar subsystems each approximate a (),2() m diameter cylinder that is 0.5 m long. The UVS approximates a cylinder that is 0.2m in diameter by .38 m long. The dimensions of the magnetometer sensor are 5.4 X 6.1 X 11.4 cm. The magnetometer electronics approximates a 15 X 16 X 18 cm box.

6.1 *Telescope Subsystem*

The telescope is a 3 mirror anastigmat supplied by OCA inc. which has extensive heritage in military programs including brilliant pebbles and Clementine. The telescope aperture is 15 cm. The focal ratio is f/2.35 with an effective focal length of 35 cm. The total field of' view is 2.5 degrees and IFOV is 43 microradians. This will provide 1 km resolution imaging at apoherm (1 [)000" 1<111). The camera will be a 1024 x 1024 CCD imager. It will incorporate an eight position filter wheel covering the wavelength range of 0.35 to 1.1 microns.

6.2 *Ultraviolet Spectrometer Subsystem*

This instrument is a simplified version of the UVS that is currently on board the Galileo spacecraft. It will have two channels with a wavelength range of 0.11 to .40 microns with a 15 Angstrom resolution. The instrument will be coaligned with the telescope axis. Light will enter the UVS through a 250 mm focal length 50 mm aperture telescope and will be constrained by a 0.1 degree X 0.1 degree aperture which will be boresighted along the telescope subsystem field of view. This instrument will permit spectra to be taken for selected regions of Mercury's surface at a best case resolution of about 250 m. It will be supplied by the Laboratory for Atmospheric and Space Physics at the University of Colorado.

6.3 *Lidar Subsystem*

The lidar system is derived from a Brilliant Pebbles- Clementine design and will be supplied by the OCA corporation. It has a Nd:TAG laser that is coaligned with the telescope. It operates at 10 Hz and delivers 180 mJ per pulse at 1.064 microns. The lidar detector will be equipped with a silicon photoavalanche diode which will permit both the timing and the strength of the returned signal to be determined. This will permit both ranging and photometric observations to be undertaken.

6.4 *Particles* (171clh'iclds bs7ills?/sic?)?

The magnetometer is a triaxial fluxgate magnetometer. '] '11(' sensors are boom mounted, and the electronics are mounted on the spacecraft. Its design will be derived from the magnetometers that were on board the Pioneer Venus and Galileo spacecraft, in addition to the ISTP/Polar and FAST Explorer programs. The magnetometers will be supplied by UCLA. In addition to the magnetometer, the subsystem will include a miniature plasma analyzer supplied by Los Alamos National Laboratory and a Plasma wave detector supplied by TRW. The plasma analyzer will provide information on the distorting influence of the solar wind and will measure the abundance of the ions and electrons. The plasma wave detector will provide diagnostics of the plasma processes and may be able to provide absolute electron density measurements. This entire ensemble of instruments will be integrated into one package and will interface with the spacecraft through a common bus.

7.0 OPERATIONS

Mission operations will be designed using JPL multimission capabilities in order to maximize inheritance and decrease development costs. The existing and planned tracking telemetry and command systems supported by the Deep Space Network will be used. The primary plan is to share operations with the Voyager operations team. By doing this, we will minimize the cost of skilled personnel required for routine operations and minimize the cost of developing a new mission operations system. This approach is well suited for Hermes and Voyager because neither mission has a unique operations system, the missions do not share peak activity periods, and the labor requirements of each mission are similar. The Hermes-Voyager mission operations concept is described in further detail by Spradlin, Linick and Horn (this meeting).

8. MANAGEMENT

An important requirement for a low cost mission is to reduce the level of organizational complexity and thereby create a structure which will permit the team to make decisions rapidly and with great efficiency. An important step in this process is to define a new partnership between the national laboratories and industry. In order to do this for Hermes, the Principal investigator has will enter into a tripartite agreement with JPL and TRW with additional contracts being let to Universities and industry for payload instruments.

The Hermes mission will be managed by a three party consortium consisting of Robert M. Nelson the Hermes Principal Investigator, The Jet, Propulsion Laboratory, and TRW corporation. The Principal Investigator will be responsible for the overall mission business, financial, technical and scientific management of the project and will have appropriate decision authority.

The Principal Investigator will chair a three member oversight board consisting of himself, and one representative each from JPL and TRW. They will regularly review the progress of the project and will assist in the appointment of key management personnel.

9. CONCLUSIONS

The Hermes study has found that sending a small planetary orbiter to Mercury is possible using a Delta II launch vehicle combined with a spacecraft and instruments with proven space heritage. In addition, such a mission requires that the team size be kept small with team members assuming multiple responsibilities which cross disciplinary lines.

The Discovery mission concept has challenged us to reexamine fundamental ideas regarding the methodology of solar system exploration. We have responded to this challenge by developing a limited, yet robust, set of scientific goals. This has been done by having scientists work collaboratively with engineers and managers who have been included from the start of the Hermes study process. To oversee this mission we have developed a management structure which permits greater visibility into each project subdivision without sacrificing management efficiency.

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