PERGAMON

Available online at www.sciencedirect.com

ScienceDirect

Acta Astronautica 63 (2008) 68–73

ACTA ASTRONAUTICA

www.elsevier.com/locate/actaastro

The MESSENGER mission to Mercury: Status after the Venus flybys

Ralph L. McNutt Jr.[a,*], Sean C. Solomon[b], David G. Grant[a], Eric J. Finnegan[a], Peter D. Bedini[a], the MESSENGER Team

[a]*The Johns Hopkins University Applied Physics Laboratory, 11100 Johns Hopkins Road, Laurel, MD 20723, USA*
[b]*Department of Terrestrial Magnetism, Carnegie Institution of Washington, 5241 Broad Branch Road, N.W., Washington, DC 20015, USA*

Abstract

NASA's MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) spacecraft, launched on 3 August 2004, is well into its voyage to initiate a new era in our understanding of the terrestrial planets. The mission, spacecraft, and payload are designed to answer six fundamental questions regarding the innermost planet during three flybys and a one-year-long, near-polar-orbital observational campaign. The cruise phase to date has been used to commission the spacecraft and instruments and begin the transition to automated use of the instruments with on-board, time-tagged commands. An Earth flyby one year after launch, a large propulsive maneuver in December 2005, and Venus flybys in October 2006 and June 2007 began the process of changing MESSENGER's heliocentric motion. The second Venus flyby was also used to complete final rehearsals for Mercury flyby operations in January 2008 while coordinating observations with the European Space Agency's Venus Express mission. The upcoming Mercury flyby will be the first since that of Mariner 10 in 1975. Along with the second and third MESSENGER flybys in October 2008 and September 2009, that flyby will provide images of the hemisphere of Mercury never seen before by spacecraft as well as the first high-resolution information on Mercury's surface mineralogy. These three flybys, interspersed with deep space maneuvers, finish adjusting the spacecraft motion sufficiently for Mercury orbit injection to follow in March 2011. In the orbital phase, the spacecraft's nominal periapsis latitude of 60°N will gradually drift northward as the periapsis altitude of 200 km gradually drifts upward due to solar gravitational perturbations. The 12-h period and 80° inclination are maintained while the altitude is readjusted downward to 200 km every Mercury revolution about the Sun. The profile enables mapping of the entire planet and acquiring detailed elemental and topographic data over the northern hemisphere. After conclusion of the nominal mission in March 2012, an additional year of data analysis and archiving is planned before the conclusion of the MESSENGER project. To broaden scientific participation in the mission, NASA has established a Participating Scientist Program, bringing a full complement of international scientific researchers into the mission. The MESSENGER team is also continuing its informal interaction with members of the BepiColombo project to maximize the overall scientific return from both missions.

1. Introduction

The MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) mission is the first robotic spacecraft to launch to Mercury since the Mariner 10 mission of over 30 years ago. Following the Mariner 10 mission and its three flybys of Mercury, the challenge was to determine how to insert a spacecraft into orbit about Mercury with an appropriate science payload [1].

Subsequently, a NASA Science Working Team studied a Mercury orbital mission, and concepts for Mercury missions were proposed at the first Discovery Program workshop in 1992. The MESSENGER mission was

---

[*] Corresponding author.
E-mail address: ralph.mcnutt@jhuapl.edu (R.L. McNutt).

0094-5765/$ - see front matter © 2008 Published by Elsevier Ltd. All rights reserved.
doi:10.1016/j.actaastro.2007.12.062

proposed under the Discovery Program in both 1996 and 1998 before being selected for flight [2]. Details of the mission scientific objectives and implementation [3], the payload [4], and mission and spacecraft design [5] at the time of selection and beginning of development have been discussed elsewhere.

2. Ongoing mission

2.1. Launch

MESSENGER, the seventh mission of NASA's Discovery Program of competed scientific missions, was launched on 3 August 2004 from Space Launch Complex 17 at the Cape Canaveral Eastern Test Range (Fig. 1).

Following spacecraft and instrument commissioning, plans focused on using the Earth flyby to obtain initial data from some of the spacecraft instruments.

Fig. 1. MESSENGER launch from Pad 17B of Cape Canaveral Air Force Station, 3 August 2004, 02:15:56.537 Eastern Daylight Time.

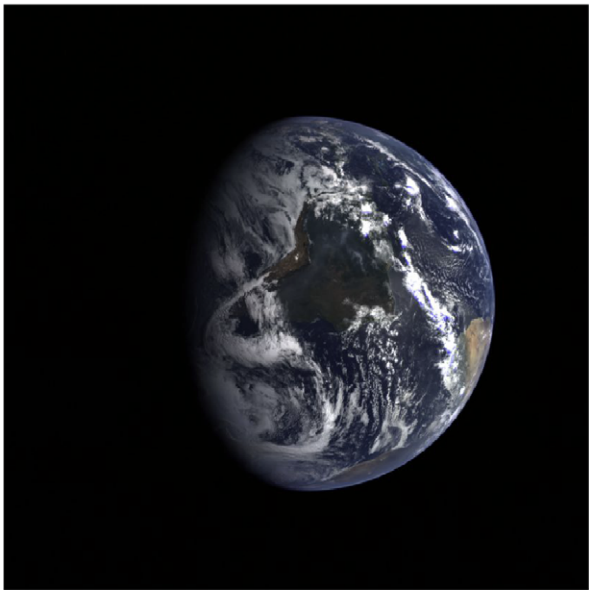

Fig. 2. Image of the Earth from the MDIS WAC taken on approach to the Earth flyby. Closest approach occurred 2 August 2005, 3:13:08 PM EDT, at 2348 km altitude over Mongolia.

2.2. Return to Earth

Among observations made during MESSENGER's Earth flyby on 2 August 2005 were images of Earth by the Mercury Dual Imaging System (MDIS), including a movie of 358 frames (one color frame per 4 min for almost 24 h), spectral measurements of the Moon by the Mercury Atmospheric and Surface Composition Spectrometer (MASCS) for later calibration of Mercury measurements, Magnetometer (MAG) measurements of the Earth's magnetic field to complete a detailed calibration and alignment check of the instrument, and particle measurements in the Earth's radiation belts by the Energetic Particle and Plasma Spectrometer (EPPS), with focus on measurements of the electrons for final calibration. All calibration results were met with excellent success.

The images of the Earth (Fig. 2) confirmed the operation of both cameras, including the color capability of the wide-angle camera (WAC). Images taken even from distances of tens to thousands of kilometers showed considerable detail (Fig. 3).

2.3. Cruise to Venus

2.3.1. Venus flyby 1

The initial gravity assist at Earth was followed by a deep-space maneuver (DSM) on 12 December 2005 to

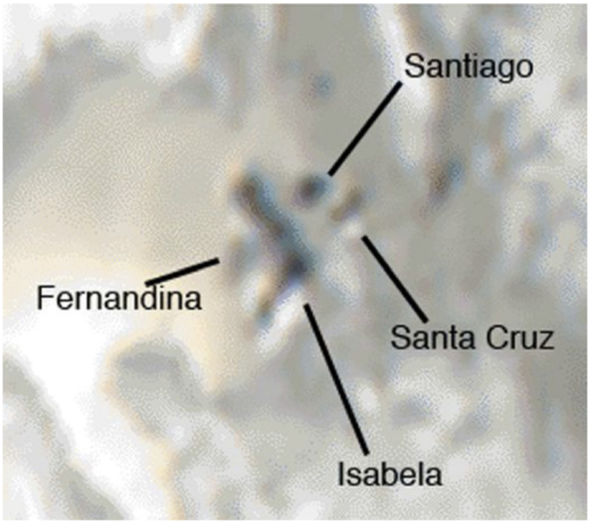

Fig. 3. MDIS WAC image of the Galápagos Islands taken on approach to the Earth flyby at a distance of 56,000 km.

line up the spacecraft for the next gravity assist, this time at Venus. MESSENGER's first gravity assist at Venus occurred at 04:34 EDT on 24 October 2006. The flyby was at a relatively high altitude (2987 km), included a long eclipse by Venus, and occurred during a period of solar conjunction. Given these conditions, it was decided that the best approach was not to plan on payload use, deferring observations using Venus for calibration to the second gravity assist there.

A spacecraft safing event occurred just prior to the Venus flyby and eclipse that has been traced to a single-event upset (SEU). The spacecraft performed as designed, yielding an excellent—albeit unplanned—test of the spacecraft safing and autonomy system.

2.3.2. Venus flyby 2

The second Venus gravity assist in June 2007 was planned as a "full dress rehearsal" for the first flyby encounter of Mercury by a spacecraft since Mariner 10's third and final flyby on 16 March 1975. Initial ground planning for the spacecraft command loads began 23 February 2007, with a critical design review (CDR) that included external, independent reviewers on 18 April. The command loads for the encounter were sent to the spacecraft on 1 and 4 June prior to the closest approach on 5 June.

As with the previous planetary encounters, the overriding requirement of this Venus flyby was to shed spacecraft energy and angular momentum with respect to the Sun, tightening the spacecraft heliocentric trajectory for eventual orbit insertion at Mercury. The flyby was successful and extremely accurate; MESSENGER was on course for the second DSM on 17 October 2007 prior to the first flyby of Mercury in January 2008.

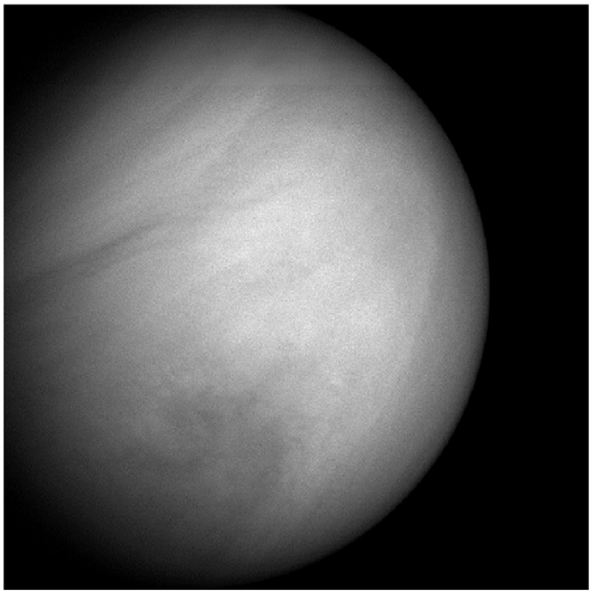

Fig. 4. Venus seen during departure at 630 nm. The image has been stretched significantly to bring out the cloud structure.

The subsidiary goals for the flyby of Venus included instrument calibrations, practice for operations during the first Mercury flyby, and doing "science of opportunity," including coordinated observations with the Venus Express mission of the European Space Agency (ESA) that has been operating in a 24-h elliptical orbit about Venus since 11 April 2006.

All operations went extremely well. The exercise was extremely helpful in confirming the applicability of the basic planned operations approach while revealing how some procedures and processes could be further optimized. In particular, the coordination of the guidance and control (G&C) operations with required MDIS gimbal operations for pointing both the WAC and the narrow-angle camera (NAC) for large-frame imaging (Fig. 4) and mosaicking (Fig. 5) were validated.

All instruments in the payload were turned on and operated with the sole exception of the cryocooler for the Gamma-Ray and Neutron Spectrometer (GRNS). In addition to requiring tens of hours to cool the germanium crystal to operational temperature, the time spent close to the planet was too short to accumulate a statistically significant number of counts. The Gamma-Ray Spectrometer (GRS) active shield was turned on as practice for Mercury operations and to measure planetary neutrons. The Neutron Spectrometer (NS) section was turned on to (1) measure planetary neutrons for the first time with the MESSENGER NS,

(2) use Venus neutrons for understanding systematic variations in neutron measurements, and (3) look for transient signals that could be associated with Venus lightning. The GRS did not detect any obvious signals but did see an increase in neutrons and Compton emission associated with Venus while detecting a decrease in galactic-cosmic-ray-associated signal as the planet shielded the instrument during closest approach. The NS also detected neutrons but no transient events.

The X-Ray Spectrometer (XRS) was also powered to look for emission of X-rays from Venus. The low-energy cutoff of ∼ 1 keV prevented seeing the principal source of atmospheric X-rays from Venus [6], and no emissions were seen. A general decrease in count rates was seen as the planet cut off the X-ray sky background near closest approach to Venus (Fig. 6).

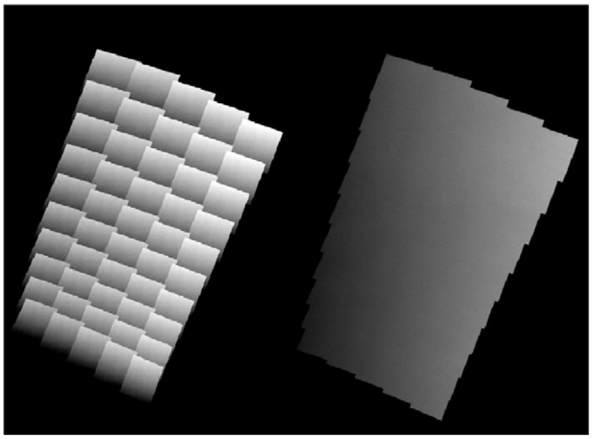

Fig. 5. NAC mosaic of the Venus clouds. On the left the edges of each frame have been exaggerated to check pointing and alignment; the mosaic with calibrations applied is on the right.

Both radio science (RS) and the Mercury Laser Altimeter (MLA) were also in operation, the first to test procedures and data acquisition that will be important in refining Mercury's second harmonic degree and order gravity field, and the second to attempt to probe the upper layers of Venus's clouds. The ranging operations of MLA were carried out during a 13-min interval, and an analysis of signatures of the received photons is underway.

The Energetic Particle Spectrometer (EPS) section of the EPPS was turned on but saw no strong signals of energetic particles or the bow shock. The Fast Imaging Plasma Spectrometer (FIPS) detected a region of solar wind flow away from the radial direction from the Sun prior to the encounter as well as possible signatures of pick-up ions. More detailed analyses of these data as well as magnetic field data from the MESSENGER MAG are ongoing. Comparisons are also being made with the relevant data sets acquired by Venus Express instruments in collaborative efforts.

Objectives for both the Ultraviolet and Visible Spectrometer (UVVS) and the Visible and Infrared Spectrograph (VIRS) components of MASCS included completing flat-field and scattered-light observations as well as providing for scientific observations and testing

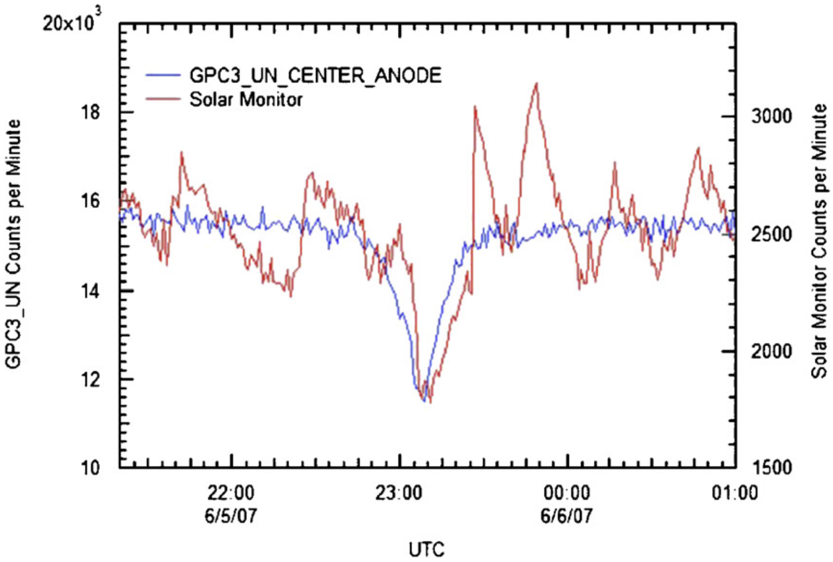

Fig. 6. XRS flux during the second Venus flyby. The blue trace shows the decrease of flux associated with the planet. The red trace shows nominal Sun-pointing solar monitor counts.

observing sequences for the Mercury flybys. VIRS detected atmospheric absorption bands, as expected, on the dayside of the planet, and UVVS detected Lyman-α and OI 130.4-nm emissions on the dayside as well as SO_2 absorption. On the nightside, the UVVS detected Herzberg emissions from O_2.

MDIS calibration efforts were focused on final flat-field calibration (Venus is an excellent extended target in the visible) and scattered-light calibration (especially for the NAC). The imaging sequences were also planned to attempt imaging of the surface with the 1000- and 1020-nm filters of the WAC on the nightside of the planet, similar to results reported from Venus Express. This successful effort is also contributing to an ongoing collaborative study by the MESSENGER and Venus Express science teams.

3. Mercury flybys

The planning for the first Mercury flyby, that occurred on 14 January 2008, began with a preliminary design review (PDR) for payload operations on 14 May 2007, prior to Venus flyby 2. Planning operations culminated with the upload of the encounter sequence during the week of 7 January 2008. Interspersed with this effort were the solar conjunction period (25 October–11 December), DSM-2 and its backup (not needed), other trajectory-correction maneuvers (TCMs), and orbital phase “day-in-the-life” (DITL) testing.

The first Mercury flyby, using procedures, processes, and spacecraft flight commands vetted during the second Venus flyby, provided the next planetary gravity assist at a planned nominal altitude of 200 km. In addition, this encounter has provided the first view of Mercury with the MESSENGER payload, including a large part of the planet not seen by Mariner 10 and imaged only coarsely (∼ 200-km resolution at visible wavelengths) from Earth.

Following the first flyby, two additional Mercury flybys on 6 October 2008 and 29 September 2009 will further shape the orbit while also allowing for observations of the opposite hemisphere of the planet from that viewed during the first flyby. These gravity assists, along with three more DSMs and a variety of smaller TCMs, will make the final required changes to the heliocentric trajectory of MESSENGER to enable orbit insertion at Mercury.

4. Orbital phase

MESSENGER’s main mission remains that of the initial proposal to NASA’s Discovery Program: orbit Mercury and seek answers to critical questions about the innermost terrestrial planet [3]. In spite of a variety of challenges—technical, managerial, and fiscal—the spacecraft launched successfully with all capabilities and payload as planned, and proposed, in 1998. The spacecraft remains on course, with propellant reserves, for injection into orbit about the innermost planet on 18 March 2011 (Fig. 7).

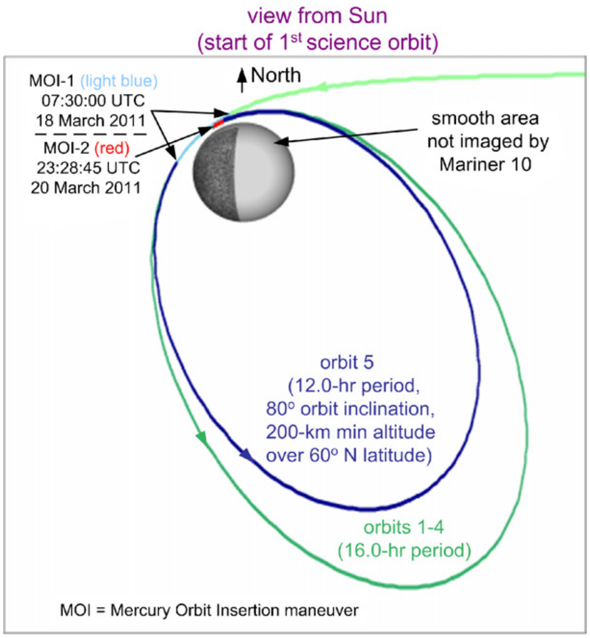

Fig. 7. Mercury orbit insertion and the first planned five orbits of the planet in March 2011. The view is from the Sun.

MESSENGER’s orbital perihelion of 0.33 AU on 1 September 2007 is close to the perihelion of Mercury and has added to the confidence in the thermal design of the spacecraft, with actual temperature readings closely tracking the pre-flight design predictions.

MESSENGER’s nominal operation in Mercury orbit is funded for one Earth year. Further operations during an extended mission phase are possible with current propellant margins and continued spacecraft health. The MESSENGER project is funded for final data archiving and analysis for one full year following discontinuation of operations in Mercury orbit. Eventually, solar gravitational perturbations will lead to the impact of MESSENGER on Mercury’s surface—the first human object to reach this (currently) little-known planet.

Acknowledgments

“The MESSENGER Team” includes hundreds of scientists, engineers, designers, technicians, support personnel, subcontractors, and managers too numerous to enumerate. We also acknowledge the assistance of NASA personnel and others who gave of their time to help review the program and enable MESSENGER to be on its way to Mercury. Details on the mission overall, flybys, and Mercury orbit insertion are maintained and updated at the MESSENGER web site: http://messenger.jhuapl.edu/. The MESSENGER effort is supported by the NASA Discovery Program under contract NAS5-97271 at the Johns Hopkins University Applied Physics Laboratory and NASW-00002 at the Carnegie Institution of Washington.

References

[1] S.A. Stern, F. Vilas, in: F. Vilas, C.R. Chapman, M.S. Matthews (Eds.), Mercury, University of Arizona Press, Tucson, 1988, p. 24.

[2] R.L. McNutt Jr., S.C. Solomon, R.E. Gold, J.C. Leary, the MESSENGER Team, Advances in Space Research 38 (2006) 564.

[3] S.C. Solomon, R.L. McNutt Jr., R.E. Gold, M.H. Acuña, D.N. Baker, W.V. Boynton, C.R. Chapman, A.F. Cheng, G. Gloeckler, J.W. Head III, S.M. Krimigis, W.E. McClintock, S.L. Murchie, S.J. Peale, R.J. Phillips, M.S. Robinson, J.A. Slavin, D.E. Smith, R.G. Strom, J.I. Trombka, M.T. Zuber, Planetary and Space Science 49 (2001) 1445.

[4] R.E. Gold, S.C. Solomon, R.L. McNutt Jr., A.G. Santo, J.B. Abshire, M.H. Acuña, R.S. Afzal, B.J. Anderson, G.B. Andrews, P.D. Bedini, J. Cain, A.F. Cheng, L.G. Evans, W.C. Feldman, R.B. Follas, G. Gloeckler, J.O. Goldsten, S.E. Hawkins III, N.R. Izenberg, S.E. Jaskulek, E.A. Ketchum, M.R. Lankton, D.A. Lohr, B.H. Mauk, W.E. McClintock, S.L. Murchie, C.E. Schlemm II, D.E. Smith, R.D. Starr, T.H. Zurbuchen, Planetary and Space Science 49 (2001) 1467.

[5] A.G. Santo, R.E. Gold, R.L. McNutt Jr., S.C. Solomon, C.J. Ercol, R.W. Farquhar, T.J. Hartka, J.E. Jenkins, J.V. McAdams, L.E. Mosher, D.F. Persons, D.A. Artis, R.S. Bokulic, R.F. Conde, G. Dakermanji, M.E. Goss Jr., D.R. Haley, K.J. Heeres, R.H. Maurer, R.C. Moore, E.H. Rodberg, T.G. Stern, S.R. Wiley, B.G. Williams, C.L. Yen, M.R. Peterson, Planetary and Space Science 49 (2001) 1481.

[6] K. Dennerl, V. Burwitz, J. Englhauser, C. Lisse, S. Wolk, Astronomy and Astrophysics 386 (2002) 319.