# Magellan Description

## Mission Overview

The Magellan spacecraft was launched from the Kennedy Space Center on 4 May 1989. The spacecraft was deployed from the Shuttle cargo bay after the Shuttle achieved parking orbit. Magellan, using an inertial upper stage rocket, was then placed into a Type IV transfer orbit to Venus where it carried out radar mapping and gravity studies starting in August 1990. The Mission has been described in many papers including two special issues of the Journal of Geophysical Research (Venus Radar Mapper Project Plan, 1983; Saunders et al., 1990; Magellan at Venus special issues, 1992). The radar system is also described in Johnson (1990).

Magellan was powered by single degree of freedom, sun-tracking, solar panels. The spacecraft was 3-axis stabilized by reaction wheels using gyros and a star sensor for attitude reference. The spacecraft carried a solid rocket motor for Venus orbit insertion. A small hydrazine system was used for trajectory corrections and certain attitude control functions. Earth communication with the Deep Space Network (DSN) was by means of S- and X-band channels. The high-gain antenna also functioned as the SAR mapping antenna during orbital operations.

The interplanetary cruise phase lasted until 10 August 1990. During the cruise phase there were small trajectory correction maneuvers to ensure proper approach geometry. Using the solid rocket motor, the spacecraft was placed into an elliptical orbit around the planet, with a periapsis latitude of approximately 10 degrees north, a periapsis altitude of 295 km, a period of 3.263 hours, and an apoapsis altitude of approximately 7762 km.

After orbit insertion, the radar system acquired test data. Then, unexpectedly, the signal from the spacecraft was lost twice. Following an intense recovery process, commands were sent to avoid further communication interruptions, and the spacecraft resumed mapping operations on 15 September 1990.

Each mapping cycle lasted 243 days, which was the time required for Venus to make one rotation under the spacecraft orbit. The first mapping cycle ended on 15 May 1991. Typical activities during a single mapping pass on Cycle 1 were as follows. As the spacecraft neared periapsis, it was oriented so the high-gain antenna pointed slightly to the side of the ground track. At a true anomaly of -59 degrees, the radar was commanded on. The radar continued to take data to a true anomaly of 80 degrees and then the radar was commanded off. On the next pass the swath started at -80 degrees and went to 59 degrees. Alternating north and south swaths were repeated throughout Cycle 1.

The range of latitudes covered by the synthetic aperture radar (SAR) during Cycle 1 was 67 degrees S to 90 degrees N. The range of SAR incidence angles was from just under 20 to just over 40 degrees. The SAR data were taken at a data rate of 750 kilobits/second and were stored in the spacecraft tape recorder. Altimeter and radiometer data were also taken when SAR data were acquired. The altimeter data were taken using a small fan beam antenna at a data rate of 30 kb/s. As the spacecraft moved away from the planet toward apoapsis, the spacecraft reoriented the high-gain antenna towards Earth and the stored radar data were transmitted to DSN stations. This data taking- and transmitting-cycle was repeated for every orbit. By 15 May 1991, the planet had been completely mapped except for the area near the South Pole and a few regions which had been missed because of temporary equipment failures.

Cycle 2 observations focused on filling the gaps in Cycle 1 coverage (including the south pole area), acquiring SAR data at a constant incidence angle (25 degrees), and conducting a suite of ad hoc experiments, including high resolution imaging and radar stereo. To observe the south pole the spacecraft was rotated 180 degrees about its nadir-pointing axis so as to conduct right-looking SAR observations. Gaps in the Cycle 1 coverage were filled by rotating the spacecraft back to its initial left-looking direction. The orbit plane was adjusted slightly at the beginning of Cycle 2 so that altimetry tracks would be offset by about 10 km at the equator, bisecting the  
orbit-to-orbit offset of altimetry tracks in Cycle 1. The spacecraft was rotated 90 deg about the HGA boresight on orbits 3716-3719 to obtain SAR and radiometry data with VV polarization. Radio occultation measurements were made on orbits 3212-3214.

The principal objective of Cycle 3 was to perform radar stereo mapping of the Venusian surface. About 30 percent of the Cycle 1 coverage was remapped in this cycle with a different, left-looking incidence angle on the surface. Gravity data were collected over Artemis Chasma. In addition, high resolution altimetry data were collected by pointing the high gain antenna straight down during orbits 4919 to 4921. Transmission of acquired radar data to Earth became nearly impossible after spacecraft equipment failures late in Cycle 3, and the radar was not used for science purposes after that.

Cycle 4 was used for full (360 degree) longitudinal collection of gravity data because of favorable planetary and spacecraft geometry. The cycle was extended by about ten days to  
compensate for passage of the radio ray through the Venus atmosphere during the first ten days. To improve sensitivity to gravity features, orbit periapsis was lowered on orbit 5752. Radio occultation measurements were made on orbits 6369, 6370, 6471, and 6472.

The aerobraking phase of the mission was designed to change the Magellan orbit from eccentric to nearly circular. This was accomplished by dropping periapsis to less than 150 km above the surface and using atmospheric drag to reduce the energy in the orbit. Aerobraking ended on 3 August 1993, and periapsis was boosted above the atmosphere leaving the spacecraft in an orbit that was 540 km above the surface at apoapsis and 197 km above the surface at periapsis. The orbit period was 94 minutes. The spacecraft remained on its medium-gain antenna in this orbit until Cycle 5 began officially on 16 August 1993.

During Cycles 5 and 6 the orbit was low and approximately circular. The emphasis was on collecting high-resolution gravity data. Two bistatic surface scattering experiments were conducted, one on 6 October 1993 (orbits 9331, 9335, and 9336) and the second on 9 November 1993 (orbits 9846-9848).  
   
Mission Phases

Mission phases were defined for significant spacecraft activity periods. During orbital operations a ‘cycle’ was approximately the time required for Venus to rotate once under the spacecraft (about 243 days). But there were orbit adjustments and other activities that made some mapping cycles not strictly contiguous and slightly longer or shorter than the rotation period.  
   
Prelaunch  
The prelaunch phase extended from delivery of the spacecraft to Kennedy Space Center until the start of the launch countdown.  
   
 Spacecraft Id: MGN  
 Target Name: VENUS  
 Mission Phase Start Time: 1988-09-01  
 Mission Phase Stop Time: 1989-05-04  
 Spacecraft Operations Type: ORBITER  
   
Launch  
The launch phase extended from the start of launch countdown until completion of the injection into the Earth-Venus trajectory.  
   
 Spacecraft Id: MGN  
 Target Name: VENUS  
 Mission Phase Start Time: 1989-05-04  
 Mission Phase Stop Time: 1989-05-04  
 Spacecraft Operations Type: ORBITER  
   
Cruise  
The cruise phase extended from injection into the Earth-Venus trajectory until 10 days before Venus orbit insertion.  
   
 Spacecraft Id: MGN  
 Target Name: VENUS  
 Mission Phase Start Time: 1989-05-04  
 Mission Phase Stop Time: 1990-08-01  
 Spacecraft Operations Type: ORBITER  
  
Orbit Insertion  
The Venus orbit insertion phase extended from 10 days before Venus orbit insertion until burnout of the solid rocket injection motor.  
   
 Spacecraft Id: MGN  
 Target Name: VENUS  
 Mission Phase Start Time: 1990-08-01  
 Mission Phase Stop Time: 1990-08-10  
 Spacecraft Operations Type: ORBITER  
   
Orbit Checkout  
The orbit trim and checkout phase extended from burnout of the solid rocket injection motor until the beginning of radar mapping.  
   
 Spacecraft Id: MGN  
 Target Name: VENUS  
 Mission Phase Start Time: 1990-08-10  
 Mission Phase Stop Time: 1990-09-15  
 Spacecraft Operations Type: ORBITER  
   
Mapping Cycle 1  
The first mapping cycle extended from completion of the orbit trim and checkout phase until completion of one cycle of radar mapping (approximately 243 days). Mapping orbits included in the first cycle were 373 through 2165. Orbits 2159-2171 were used for an interferometry test, and orbits 2172-2175 were used to conduct an orbit trim maneuver (OTM).  
   
 Spacecraft Id: MGN  
 Target Name: VENUS  
 Mission Phase Start Time: 1990-09-15  
 Mission Phase Stop Time: 1991-05-15  
 Spacecraft Operations Type: ORBITER  
   
Mapping Cycle 2  
The second mapping cycle extended from completion of the first mapping cycle through an additional cycle of mapping. Acquisition of ‘right-looking’ SAR data was emphasized. Orbits included in the second cycle were 2176 through 3976. Radio occultation measurements were first carried out on orbits 3212-3214. A period of battery reconditioning followed completion of Cycle 2.  
   
 Spacecraft Id: MGN  
 Target Name: VENUS  
 Mission Phase Start Time: 1991-05-16  
 Mission Phase Stop Time: 1992-01-17  
 Spacecraft Operations Type: ORBITER  
   
Mapping Cycle 3  
The third mapping cycle extended from completion of battery reconditioning through an additional cycle of mapping (approximately 243 days). Acquisition of ‘stereo’ SAR data was emphasized. Orbits included in the third cycle were 4031 through 5747.  
   
 Spacecraft Id: MGN  
 Target Name: VENUS  
 Mission Phase Start Time: 1992-01-24  
 Mission Phase Stop Time: 1992-09-14  
 Spacecraft Operations Type : ORBITER  
   
Mapping Cycle 4  
The fourth mapping cycle extended from completion of the third mapping cycle through an additional cycle of mapping. Acquisition of radio tracking data for gravity studies was emphasized. Radio occultation measurements were carried out on orbits 6369, 6370, 6471, and 6472. Because of poor observing geometry for gravity data collection at the beginning of the cycle, this cycle was extended 10 days beyond the nominal 243 days. Orbits included within the fourth cycle were 5748 through 7626. Periapsis was lowered on orbit 5752 to improve sensitivity to gravity features in Cycle 4.  
   
 Spacecraft Id: MGN  
 Target Name: VENUS  
 Mission Phase Start Time: 1992-09-14  
 Mission Phase Stop Time: 1993-05-25  
 Spacecraft Operations Type: ORBITER  
   
Aerobraking  
The aerobraking phase extended from completion of the fourth mapping cycle through achievement of a near-circular orbit. Circularization was achieved more quickly than expected; the first gravity data collection in the circular orbit was not scheduled until 11 days later. Orbits included within the aerobraking phase were 7627 through 8392.  
   
 Spacecraft Id: MGN  
 Target Name: VENUS  
 Mission Phase Start Time: 1993-05-26  
 Mission Phase Stop Time: 1993-08-05  
 Spacecraft Operations Type: ORBITER  
   
Mapping Cycle 5  
The fifth mapping cycle extended from completion of the aerobraking phase through an additional cycle of mapping (approximately 243 days). Acquisition of radio tracking data for gravity studies was emphasized. The first orbit in the fifth cycle was orbit 8393, and the last was orbit 12248.  
   
 Spacecraft Id: MGN  
 Target Name: VENUS  
 Mission Phase Start Time: 1993-08-16  
 Mission Phase Stop Time: 1994-04-15  
 Spacecraft Operations Type: ORBITER  
   
Mapping Cycle 6  
The sixth mapping cycle extended from completion of the fifth mapping cycle through an additional cycle of mapping (approximately 180 days). Acquisition of radio tracking data for gravity studies was emphasized. The first orbit in the sixth cycle was orbit 12249, and the last was orbit 15032. The sixth cycle ended when radio contact was lost as the spacecraft entered the atmosphere and was destroyed in a ‘terminal windmill’ experiment.  
   
 Spacecraft Id: MGN  
 Target Name: VENUS  
 Mission Phase Start Time: 1994-04-16  
 Mission Phase Stop Time: 1994-10-12  
 Spacecraft Operations Type: ORBITER  
  
Mission Objectives

*Volcanic and Tectonic Processes*  
Magellan images of the Venus surface show widespread evidence for volcanic activity. A major goal of the Magellan mission was to provide a detailed global characterization of volcanic landforms on Venus and an understanding of the mechanics of volcanism in the Venus context. Of particular interest was the role of volcanism in transporting heat through the lithosphere. While this goal will largely be accomplished by a careful analysis of images of volcanic features and of the geological relationships of these features to tectonic and impact structures, an essential aspect of characterization will be an integration of image data with altimetry and other measurements of surface properties.

Explosive pyroclastic volcanism should not occur in the present Venus environment, unless the magma contains amounts of volatiles that are large by terrestrial experience. Thus, evidence for extensive pyroclastic deposits would imply the presence of large amounts of volatiles or, if the deposits are old, may suggest historic changes in atmospheric density. Such ideas can be tested using SAR and altimetry data, combined with knowledge of the local geopotential field and may shed light on magma dynamics. Measurements of longitudinal and transverse slope, flow margin relief, and flow surface relief also provide powerful constraints on flow models, as well as on the rheological properties and physical state of the lava.

A parallel goal was the global characterization of tectonic features on Venus and an appreciation of the tectonic evolution of the planet. This goal addressed issues on several scales. On the scale of individual tectonic features is the mechanical nature of the faulting process, the documentation of geometry and sense of fault slip, and the relationship between mechanical and thermal properties of the lithosphere. On a somewhat broader scale is linking groups of features to specific processes (e.g., uplift, orogeny, gravity sliding, flexure, compression or extension of the lithosphere) and testing quantitative models for these processes with SAR images and supporting topographic, gravitational, and surface compositional data. On a global scale is the question of whether spatially coherent, large-scale patterns in tectonic behavior are discernible, patterns that might be related to an organized system of plates or to mantle convective flow.

For more information on volcanic and tectonic investigations see papers by Head et al. (1992) and Solomon et al. (1992), respectively.   
  
*Impact Processes*  
The final physical form of an impact crater has meaning only when the effects of the cratering event and any subsequent modification of the crater can be distinguished. To this end, a careful search of the SAR images can identify and characterize both relatively pristine and degraded impact craters, together with their ejecta deposits (in each size range) as well as distinguishing impact craters from those of volcanic origin. The topographic measures of depth-to-diameter ratio, ejecta thickness distribution as a function of distance from the crater, and the relief of central peaks contribute to this documentation.

It is expected that several time-dependent processes influence the change in appearance of craters with increasing crater age, including continued bombardment of the surface, variations in the mechanical properties of the lithosphere (as a result of cooling or loss of near-surface volatiles), horizontal deformation of the lithosphere, possible variations in the mass of the atmosphere, volcanism, and finally, surface erosion and deposition. Distinguishing and understanding these processes constitute important components of the study of crater morphology.

Beyond their intrinsic interest in providing a record of impact and deformational processes, craters provide a tool for the relative dating of surface geological units. Relative ages can be established from a comparison of the variations in the areal density of craters of a given size as well as from a comparison of the maximum extent to which different craters are degraded. Together with superpositional relationships (a lava flow that covers an older fault) and transectional relationships (a graben that cuts through an older volcano), the relative temporal evolution of large areas of the Venus surface can be reconstructed.

For more information on investigations of impact processes see Schaber et al. (1992).   
  
*Erosional, Depositional, and Chemical Processes*  
The nature of erosional and depositional processes on Venus is poorly known, primarily because the diagnostic landforms typically occur at a scale too small to have been resolved in Earth-based or Venera 15/16 radar images. Magellan images show wind eroded terrains, landforms produced by deposition (dune fields), possible landslides and other down slope movements, as well as aeolian features such as radar bright or dark streaks 'downwind' from prominent topographic anomalies. One measure of weathering, erosion, and deposition is provided by the extent to which soil covers the surface (for Venus, the term soil is used for porous material, as implied by its relatively low value of bulk dielectric constant). The existence of such material, and its dependence on elevation and geologic setting, provide important insights into the interactions that have taken place between the atmosphere and the lithosphere.

Because of the inference drawn from the deuterium-to-hydrogen ratio of the present atmosphere for the past existence of substantial amounts of water on Venus, radar images continue to be searched for evidence of past episodes of fluvial activity (drainage systems) and for lake beds and coastal signatures (strandlines).

The existence of a thick and cloudy atmosphere precludes infrared, visual, ultraviolet, x-ray, or gamma-ray observation of the Venus surface from orbit. Thus it is impossible to obtain information on a global basis about the surface composition or mineralogy using remote-sensing techniques at these wavelengths. Pioneer Venus and Magellan have disclosed that very often the surfaces of elevated regions possess both anomalously high values of normal-incidence radar reflectivity, occasionally exceeding 0.43, and associated low values of radio emissivity, reaching as low as 0.50. In the absence of liquid water, which is known from a variety of evidence not to be present today on Venus, it is necessary to assume a surface composition that would be unusual in terrestrial experience to explain values of dielectric constant implied by these observations. The most acceptable of the current hypotheses requires a significant number of electrically conducting elements in surface materials. If these are iron sulfides, as some chemical evidence suggests, they may possibly be brought to the surface by volcanic activity. The good spatial resolution of the Magellan instrumentation, both in determining the surface reflectivity from the altimetric observations and in measuring the emissivity from radiometric observations, promises to outline the structure of these regions and may shed light on their origin. Results will be applied to testing hypotheses for regional and global buffering of atmospheric composition by reactions with crustal materials.

For more information on erosional, depositional, and chemical processes see papers by Arvidson et al. (1992), Greeley et al. (1992), and Greeley et al. (1994).   
  
*Isostatic and Convective Processes*  
Topography and gravity are intimately and inextricably related, and must be jointly examined when undertaking geophysical investigations of the interior of a planet, where isostatic and convective processes dominate. Topography provides a surface boundary condition for modeling the interior density of Venus.

Modeling of the interior density using gravity data is, of course, nonunique. Meaningful interpretation rests on integrating other data sets and/or incorporating specific mechanical models of the interior. For example, a single density interface underlying the known topography can be found that exactly matches any observed gravity field. The interface can be at any depth; the greater the depth, the larger the density contrast needed.

The thickness of the elastic lithosphere of Venus, i.e., the outer region of the planet that behaves elastically over geologically long periods of time, is of special interest. The base of this zone is likely to be defined by a specific isotherm whose location depends on the particular temperature-dependent flow or creep properties of the material underneath. If this isotherm can be mapped in space and time, then models for the thermal evolution of the planet can be developed.

The key to determining lithospheric thickness variations in space and time is through flexure studies. If a mass load, e.g., a shield volcano or a mascon, is placed on the planetary surface, then the elastic lithosphere will flex under the load. The controlling parameter is the flexural rigidity, which is dependent on the elastic constants and lithospheric thickness.

Crucial to applying estimates of flexural rigidity to the task of unraveling the thermal history is an estimate of when the load was emplaced. Thus age determinations derived by various geologic techniques are essential to this scheme.

For more information on topography and gravity see papers by Ford and Pettengill (1992), Special Issue (1994), Konopliv et al. (1993), and [McNamee et al. (1993).  
  
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