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Beyond Aerobraking: Designing the Magellan Global Gravity Experiment

by

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The orbit of the Magellan spacecraft will be circularized by aerobraking by the end of August, 1993. The nearly circular orbit is necessary to obtain meaningful gravity science at high latitudes. This paper will describe the tradeoffs made during the design of the nearly circular orbit. Magellan is currently in an elliptical orbit ($e = 0.397$) around the planet Venus. When aerobraking begins on May 25, 1993, a small aerodynamic drag will be applied to approximately 850 orbits in order to circularize the orbit ($e < .020$).

This paper will briefly describe the Magellan mission, outline the High Resolution Gravity Science Experiment, and then describe the design tradeoffs which went into picking the desired nearly circular orbit.

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This paper presents the result of one phase of research carried out at the Jet Propulsion laboratory, California Institute of Technology under contract with the National Aeronautics and Space Administration.

Magellan Mission Description

The Magellan Mission is nearly completed. The primary mission objective to map the surface of Venus is completed, with 99°/0 of the surface imaged by a synthetic array radar, which doubled as a radiometer. A second antenna has mapped the altimetry of 98% of the surface. Three 243 day mapping cycles were devoted to the radar experiment, so some regions have been imaged three times at different look angles. Some areas very near the poles have been imaged thousand times. No further radar data will be collected. The spacecraft is currently mapping the gravity field. Although data can be obtained from the entire orbit when the Sun geometry permits, the elliptical orbit geometry limits the High resolution gravity data to a ± 40° latitude band centered *on* periapsis. Periapsis is at a latitude of 10“N.

The Magellan Spacecraft is currently in a 3.21 hour orbit around Venus. The periapsis altitude *is low* (180 Km), the eccentricity is large (0.397), and the apoapsis altitude is high (8400 Km). The orbit is inclined 85.5° to the Venus equator to make the entire surface visible to the spacecraft radar at some time during the mission. Periapsis is near the equator(10° North Latitude) and near the descending node. During the Aerobraking phase, which is scheduled to begin on May 26, 1993, aerodynamic drag will lower the orbit apoapsis by 113 Km per day, while periodic maneuvers will maintain the periapsis in a 2 Km corridor which gradually decreases from 138 Km to 130 Km. (Ref. 1 & 2) Aerobraking will be terminated by raising periapsis into the band between 180 Km and 260 Km when the apoapsis altitude reaches approximately 500 Km. Aerobraking is the only way to reach a nearly circular orbit, since the amount of propellant on board Magellan is at least an order of magnitude too small to circularize propulsively.

High Resolution Global Gravity Science Mission Objectives

The purpose of the Magellan high resolution global gravity mission is to map the global gravity field of Venus, especially at the high latitudes which were poorly resolved during the current gravity mapping phase. References 3 and 4 describe Venus gravity fields which have been produced using Magellan and Pioneer Venus Orbiter data.Once all of the gravity data sets are combined and mapped onto the topographic maps produced from the Synthetic Array Radar data, geologists and planetologists will be able to infer the types of interior processes, such as upwelling, which caused the various surface features. Gravity anomalies have been shown to be highly correlated with topography (Ref .4). The higher resolution, global gravity field which will be obtained from the post Aerobraking phase will significantly increase the ability of scientists to correctly model mantle convection and lithospheric compensation mechanisms which modify the surface features on Venus. (Ref. 5,6, 7).

Experiment Description

The gravity data is obtained by monitoring the coherent two way radio link between the spacecraft High Gain Antenna and the Deep Space Network tracking station as the spacecraft passes through periapsis. The uplink frequency provides a reference for the downlink frequency. Small, local accelerations of the spacecraft can be inferred from the signal observed at the Deep Space Network (DSN) tracking stations by comparing the sampled doppler shift of the downlink with the expected doppler shift. The expected doppler shift accounts for the gravitational accelerations of a spherical Venus, the other planets, and the Sun, aerodynamic drag, the relative motions of Earth and Venus, the rotation of the Earth about the North Pole, tropospheric and ionospheric delays and relativity. The raw tracking data are used as the observable in an orbit estimation. The residuals from the estimation process are small velocity errors. The Line of Sight acceleration *"errors"* are obtained by differentiating a spline fit of the velocity residuals. These acceleration “errors” are attributed to the local nonuniformities in the gravitational field of Venus, Models of the surface mass distribution or density can be developed to reproduce the observed tracking data. Since gravitational force decreases as the inverse-square of the distance, the gravity experiment becomes more sensitive when the spacecraft is closest to the mass variations. The resolution of the gravity experiment is approximately equal to the altitude of the orbit. Thus, the gravity experiment desires the lowest possible orbit. The highly elliptical current orbit limits the best data to a band centered on periapsis, while a nearly circular orbit enables global gravity, as illustrated by Figure 1.

Mission Constraints

Two opposing desires are driving the design of the post aerobraking orbit. Because the Magellan Project has so successfully met all of the objectives of the prime and early extended missions, funding for the circular orbit gravity mission will be a tiny fraction of the funding for the prime mission. This low funding level means that very few people will staff the project, which means that the number of maneuvers during the circular orbit phase must be small or none. Since the gravity field tends to pull the periapsis lower at the rate of approximately 20 Km per sidereal day (243 days) for achievable orbits, and since the periapsis fluctuates by nearly 60 Km, periapsis must begin at a relatively high altitude in order to avoid costly maneuvers. The scientists desire the altitude to be as low as possible, in order to maximize the resolution of the gravity data. The goal is to find an achievable orbit which wilf meet the operational constraints imposed by the reduced workforce by minimizing the number of maneuvers or eliminating maneuvers altogether while keeping the altitude as low as possible.

Figure 2 illustrates the periapsis altitudes for two possible options which illustrate some of the design tradeoffs which must be made. The lower curve represents the trajectory for a 500 x 220 Km initial orbit. Because the gravity field pulls the periapsis lower into the atmosphere, this trajectory requires a maneuver on Day 350 near midnight to remain above the dynamic pressure constraint required to remain on reaction wheels with a single desaturation per orbit. The upper curve represents the trajectory for a 500 x 260 Km initial orbit which does not require any maneuvers. The difference in the shape of the trajectories near days 200 and 450 is due to small differences in the gravity model. The upper curve represents the best available 21 by 21 gravity field, while the fewer curve is an earlier 21 x 21 field.

Figure 3 shows the apoapsis altitudes for the same two trajectories. The lower curve, which shows a noticeable decay in the apoapsis altitude, illustrates the effects of aerodynamic drag on the trajectory especially near the end when periapsis is lowest. The upper curve, which actually increases in altitude, shows that the drag effects are negligible such that the apoapsis increases as the periapsis decreases to maintain a nearly constant period.

Figure 4 shows the dynamic pressures for the two trajectories. A dynamic pressure in the range of 0.001 to 0.0025 N/m^2 will complicate operations by requiring reaction wheel desaturations more than once per orbit. The upper curve corresponds to the fewer periapsis altitude. The extremely small dynamic pressures associated with the lower curve (higher altitudes) show that the desired periapsis which requires no maneuvers fies somewhere between these two cases, which are separated by 40 Km. If one or two maneuvers are allowed, the average periapsis altitude can be lowered close to 170 Km.

Conclusions

Obtaining a high resolution, global gravity field for Venus will significantly enhance the science return from the Magellan Mission by enabling geologists and planetologists to infer the interior dynamics which lead to formation of surface features which are not associated with impact craters. Selection of the proper nearly circular orbit is essential for maximizing the resolution of the data within the very limited resources which are available to the Magellan project.

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Figure 1
Altitude versus Latitude for Circular and Elliptic Orbits

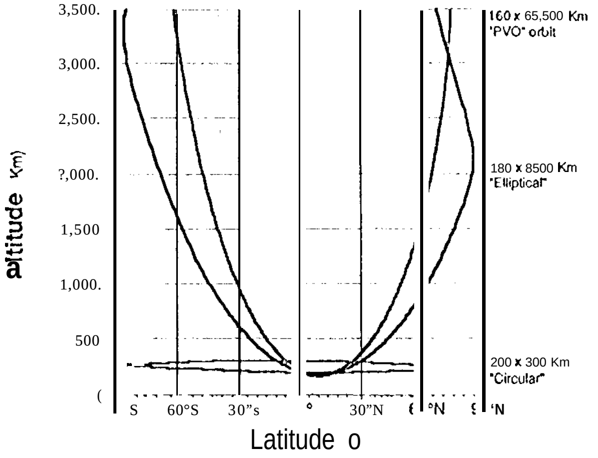

Figure 2
Periapsis Altitudes for Two Options

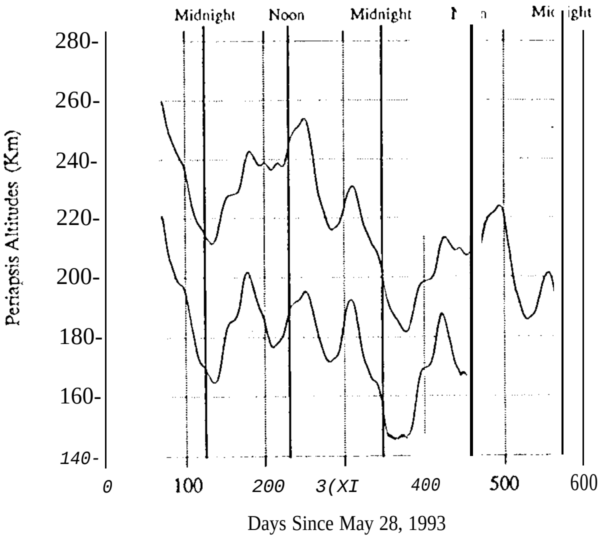

Figure 3
Apoapsis Altitudes for Two Options

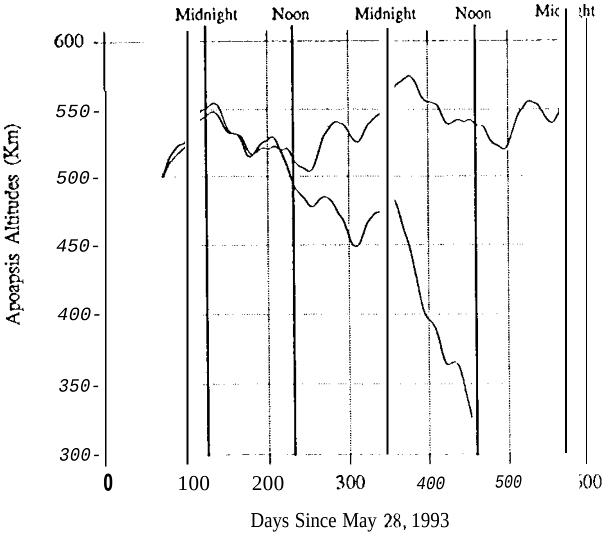

Figure 4
Dynamic Pressures for Two Options