Reports

Mariner 10 Venus Encounter

Abstract. *The Mariner 10 spacecraft encountered Venus at 1701 G.M.T. on 5 February 1974. The preplanned encounter science sequence was executed satisfactorily, accomplishing all objectives despite a number of spacecraft problems that had occurred in the early phases of the flight. Seven experiments were conducted, including observations of the solar wind interaction region, extreme ultraviolet and infrared emissions, radio occultation, and imaging.*

Mariner 10, launched at 0245 G.M.T. on 2 November 1973 encountered Venus at 1701 G.M.T. on 5 February 1974. A number of scientific objectives had been defined for the Mariner 10 flyby of Venus. Further study of the solar wind interaction with the planet was desired to obtain a better understanding of this special (ionospheric) interaction type. A detailed, dispersive (S and X band) radio occultation probe of the ionosphere and the neutral atmosphere was planned to yield data complementary to the previous American and Soviet observations. In particular, a second penetration of the scattering layer observed in the 35- to 50-km altitude region by Mariner 5 was desired. The study of extreme ultraviolet emissions from H, He, O, C, Ne, and Ar were expected to provide new information on the composition and structure of the upper atmosphere. Cloud top brightness temperature determinations and limb darkening observations in the infrared were desired at higher spatial resolution than achievable from the earth. Celestial mechanics objectives included refinements in the determination of the ephemeris, mass, and figure of the planet. The imaging experiment was designed with two major objectives in mind: (i) to search along the terminator for structure in the visible clouds during the few minutes near periapsis when the viewing geometry was ideal, and (ii) to study the Venus ultraviolet markings, known to exist at a scale of hundreds of kilometers from Earth-based observations. The camera systems were instrumented to match the near-ultraviolet wavelength at which the markings had been observed. It was hoped that the observation of these phenomena over a time period encompassing more than one rotation period (4 days) would yield important information on upper atmosphere dynamics.

Of course, the principal scientific objective of the Mariner 10 mission is the exploratory investigation of Mercury. The instruments selected for the flight (Table 1) were chosen with this in mind and were optimized for the Mercury investigations. Further, selection of the trajectory and aim point at Venus was dictated by the requirement to use the planet's gravity field as a "third stage" to achieve a Mercury encounter. Thus, a solar occultation was not possible, eliminating the extreme ultraviolet occultation spectrometer as a Venus experiment. Similarly, the location of the infrared radiometer, a body-fixed instrument, was set for the Mercury encounter geometry so that only one of its two fields of view scanned across Venus. In addition, the temperature range of the radiometer was selected for expected Mercury conditions, and useful Venus data was obtained from only one of its two wavelength channels.

Despite these limitations, Venus science has always been considered a primary mission objective, second in priority only to that of Mercury, and Venus observations figured importantly in the mission design process. In fact, the Venus science sequence, discussed below, turned out to be more complex than the one designed for Mercury. One aspect of this complexity resulted from the recognition by the radioscience investigators that the two-axis articulation of the high-gain antenna provided an opportunity for steering the dish in a way that compensated for atmospheric bending, keeping the deflected radio beam directed toward the earth. This method allowed deeper penetration into the Venus atmosphere than could be achieved with a fixed antenna and provided a usable signal minutes after entrance into and before emergence from geometric occultation.

Hardware modifications were made to the payload specifically for the Venus sequence. Because of the Venus flyby geometry, the terminator region

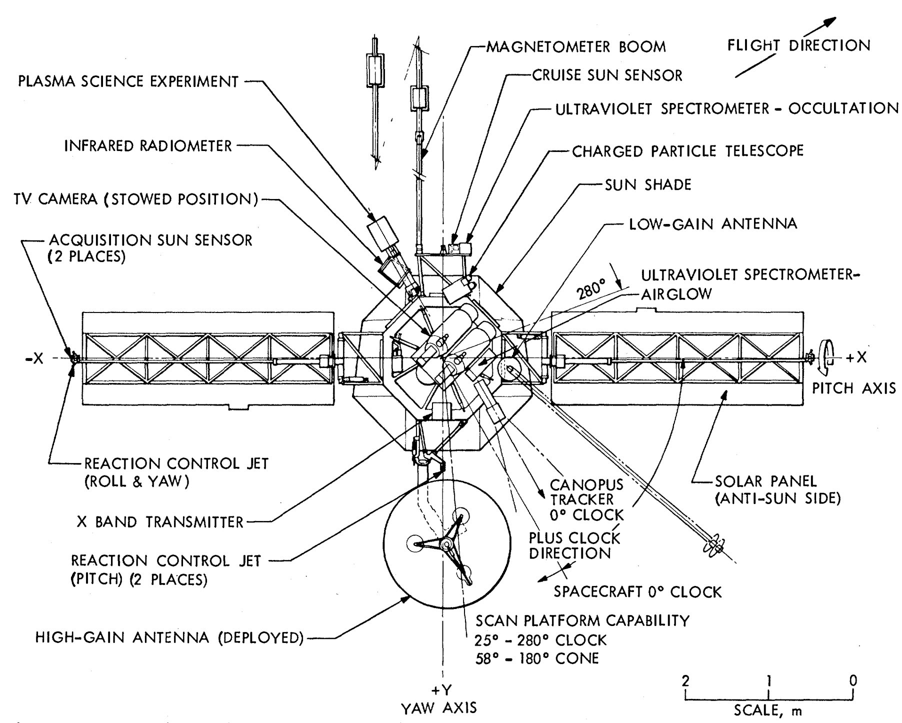

Fig. 1. The Mariner 10 spacecraft looking sunward along the spacecraft Z axis (normal to the plane of the drawing at the intersection of the X and Y axes). The dashed line drawing of the low-gain antenna shows its position for the extended mission, which starts approximately 2 weeks after Mercury encounter.

was accessible to near normal viewing for only a few minutes near closest approach. The area coverage of the two 1.5-m focal length, 1/2° by 1/3° field of view telescopes selected for Mercury photography would have been entirely too small to examine the terminator region for evidence of structure in the visible clouds at the expected scale. For this reason, wide-angle (11° by 14°) auxiliary optics were added to the television telescopes. In order to permit observations of the ultraviolet markings, near-ultraviolet filters with a bandpass between 300 and 400 nm were incorporated, and special ultraviolet-transmitting optical coatings were applied to the corrector plates of the telescopes. Ground tests conducted at Jet Propulsion Laboratory's Table Mountain Observatory verified that the Mariner 10 telescopes would produce data comparable to Earth-based observations of the Venus ultraviolet markings. Finally, the extreme-ultraviolet airglow spectrometer, originally intended as a body-fixed instrument set for Mercury limb crossings, was placed on the scan platform to allow good observing geometry at Venus.

The Mariner 10 spacecraft is shown in Fig. 1. The spacecraft system design, assembly, and test were conducted by the Boeing Aerospace Company in Kent, Washington, under the direction of the Jet Propulsion Laboratory. The design and, in fact, some of the flight hardware are derived from previous Mariners, particularly Mariners 6 through 9. Spacecraft weight at injection was 502.4 kg. Three-axis stabilization is obtained with the use of sun and Canopus celestial sensors and cold N_2 gas jets. Inertial control is provided by rate gyros in roll, pitch, and yaw. Celestial pointing geometry is referenced to cone and clock axes with the cone angles measured relative to the $+Z$ axis (sun direction) and the clock angles relative to the Canopus tracker central-view direction. Two rotatable solar panels provide electrical power. The rotating capability is required to reduce solar heating of the panels as the spacecraft approaches the orbit of Mercury by reducing the projected panel-area illuminated. For off-sun operation (as in trajectory correction maneuvers and solar occultations), a rechargeable nickel-cadmium battery provides electrical power. Communication is via a 1.37-m parabolic two degrees of freedom high-gain antenna with a combined S and X band feed, and a biconical low-gain omnidirectional antenna, which is used when the spacecraft is being maneuvered. Data rates at Venus encounter were 117.6 kbit/sec for television data and 2.45 kbit/sec for nonimaging science. A dual channel, interplex modulated telemetry system is employed to allow separate selection of high and low rate channel data rates. Complex scientific or engineering sequences, such as encounters and trajectory maneuvers, are accomplished with commands generated by a small (512 word) central computer and sequence (CC & S). The contents of the CC & S are periodically updated to conduct successive portions of the mission sequence. The first portion of the Venus encounter sequence was loaded into the CC & S on 29 January, and the remainder on 6 February, some 21 hours following closest approach. During that interval, thousands of commands were issued to various subsystems by the CC & S, whereas only a few dozen were sent from the ground. Detailed descriptions of the Venus-Mercury trajectory design and the Mariner 10 spacecraft can be found in papers by Bourke and Beerer (*1*) and Hooke (*2*), respectively.

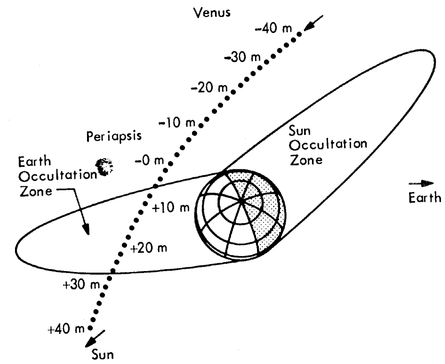

Fig. 2. Venus close flyby geometry, viewed from the trajectory north pole. Dots show spacecraft position at 2-minute intervals. Spacecraft altitude at periapsis was 5785 km.

Encounter operations began on 28 January with the turn-on and initialization of the scientific instruments. Venus encounter geometry is given in Fig. 2. The spacecraft velocity relative to Venus was 11.03 km sec^{-1}. Distances to the earth and the sun were 44.1 million and 107.5 million km, respectively. Periapsis altitude is measured relative to the solid body of radius 6052 km. The Venus flyby decreased the spacecraft's heliocentric velocity 4.41 km sec^{-1}. The trajectory was favorable for observations of the solar-wind interaction zone, as the spacecraft approached Venus from the antisolar side parallel to the extended Venus sun line, providing an opportunity for far downstream measurements. Television coverage was restricted on the approach leg, beginning with cusp photographs some 38 minutes before encounter (E_V; the time corresponding to periapsis). Terminator photography at near 90° phase angles was obtained for several minutes near closest approach by use of the wide angle accessory optical train. Following the close approach photography, near zero phase angle observations were obtained for several days, providing time-lapse monitoring of the ultraviolet markings. The infrared radiometer scanned across the disk from 40°N to 23°N latitude between $E_V - 30$ minutes and $E_V - 5$ minutes.

A number of limb crossings and high

Table 1. Mariner 10 scientific instruments.

Experiment	Principal investigator	Institution	Instrument	Weight (kg)	Power (watt)
Celestial mechanics and radio science	H. T. Howard	Stanford University	X band transmitter	1.8	10.6
Charged particles	J. A. Simpson	University of Chicago	Charged particle telescope	3.8	1.6
Extreme ultraviolet	A. L. Broadfoot	Kitt Peak National Observatory	Airglow spectrometer	3.9	3.0
			Occultation spectrometer	1.6	1.3
Infrared	S. C. Chase	Santa Barbara Research Corp.	Infrared radiometer	3.6	2.5
Magnetic fields	N. F. Ness	Goddard Space Flight Center	Triaxial fluxgate magnetometers (two)	11.5	5.5
Plasma science	H. S. Bridge	Massachusetts Institute of Technology	Scanning electrostatic analyzer and electron spectrometer	9.7	6.8
Television science	B. C. Murray	California Institute of Technology	Twin 1.5-m telescopes, vidicon cameras	43.9	30.9
			Total	79.8	62.2

atmosphere scans were obtained with the ultraviolet airglow spectrometer in the near-encounter sequence, and a series of drifts across the limb were obtained later, interleaved with television observations. The Venus encounter sequence was conducted as planned out to $E_V + 4$ days, when the television hourly cyclics were reduced to a 1-hour observing period every 8 hours, which continued until $E_V + 8$ days. It had been planned to monitor the ultraviolet markings until $E_V + 17$ days.

The high-gain antenna steering sequence discussed above was conducted during the earth occultation period. Analysis of preliminary data indicates that this technique was successful, yielding several kilometers additional penetration into the neutral atmosphere.

A number of spacecraft problems were encountered during the Mariner 10 mission. Of these, two affected the Venus encounter sequence significantly. First, the television optic heaters failed to come on shortly after launch. Thus, television instrument power had to be left on after the earth-moon calibration sequence to maintain optics temperatures within survival limits. The problem was cleared some 2 weeks before Venus encounter, but the 2 months of unplanned operation resulted in early termination of the postencounter television observations because of concern over instrument lifetime. Second, a roll gyro oscillation, which first occurred on 28 January, resulted in the cancellation of the roll calibration maneuver schedule for 12 February as a part of the Venus encounter sequence. Roll calibration maneuvers provide data which allow the determination of magnetometers zero offsets.

The roll gyro oscillation problem also resulted in the cancellation of trajectory correction maneuvers scheduled for 9 February and 1 March. A "sun-line" maneuver, that is, one in which no spacecraft attitude maneuvers are required, will be conducted in place of these maneuvers about 16 March. This change in maneuver strategy is not expected to degrade Mercury science because the mission-design aimpoint (a point which lies in both the sun and earth occultation zones at a periapsis altitude of approximately 1000 km) is still accessible. Mercury encounter will occur on 29 March between 2030 and 2100 G.M.T.

The Mariner 10 Venus encounter yielded a wealth of new information regarding the planet's atmosphere, figure, and solar wind interaction, extending and complementing results obtained by previous Mariner and Venera spacecraft. In addition to this general expansion of our knowledge, the Mariner 10 results should significantly benefit future missions to Venus. For example, the extraordinary and totally unexpected (by me at least) richness in structural detail observed in the upper atmosphere by near-ultraviolet imaging must be taken into account in selecting a strategy for remote sensing and in situ sampling of the Venus atmosphere. Similarly, the observation of apparent structureless homogeneity of the visible clouds and the existence of well-defined haze layers at their upper boundary is significant with regard to both models of the atmosphere and plans to probe it further.

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References and Notes

1. R. D. Bourke and J. G. Beerer, *Astronaut. Aeronaut.* (January 1971), p. 52.
2. A. J. Hooke, *Spaceflight* **16**, 25 (1974).
3. I thank A. L. Webb and J. Y. Pedigo of JPL for assistance in the preparation of figures and manuscript, and D. G. Rea of JPL for critical review and comment. This report represents one aspect of research carried out by JPL under NASA contract NAS 7-100.

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Preliminary Infrared Radiometry of Venus from Mariner 10

Abstract. *The intensity of emission at 45 micrometers, measured with high spatial resolution along a single crossing of the Venus disk, is presented. On the average, the observed darkening toward the limb varies nearly linearly with the cosine of the emission angle. The brightness temperature, extrapolated to normal emission, is 255°K. The limb darkening curve, interpreted in a linear approximation, implies that the atmosphere is quite opaque, with an absorption coefficient of 0.24 per kilometer. Changes in curvature present in the limb darkening curve suggest the existence of thermal inhomogeneities with scale comparable to that of the dark markings shown by ultraviolet images.*

The infrared radiometer carried on Mariner 10 was designed specifically to make measurements of Mercury. However, the flyby of Venus provided an opportunity to observe the emission from the atmosphere of Venus at a wavelength inaccessible from the earth and with a spatial resolution exceeding the best obtainable at shorter infrared wavelengths from the earth.

The radiometer is essentially the same as that flown on Mariners 6, 7, and 9 (*1*), but with modifications as necessary to accept radiation in the 8- to 14-μm and in the 35- to 55-μm wavelength intervals. The radiometer was fixed relative to the spacecraft such as to give two traversals of Mercury; the orientation of the spacecraft relative to Venus resulted in only the single swath shown in Fig. 1. At 45 μm, the radiometer's field of view subtended an angle of 1.1°, giving a maximum linear resolution of about 200 km on the planet. The dynamic range of the 11-μm channel was adjusted for observations of the lighted surface of Mercury with an expected temperature of about 700°K. As a result, these shorter wavelength measurements of Venus provided only small signals and will not be discussed further. In contrast, the 45-μm channel was designed specifically for dark-side observations of Mercury, with a dynamic range up to 320°K.

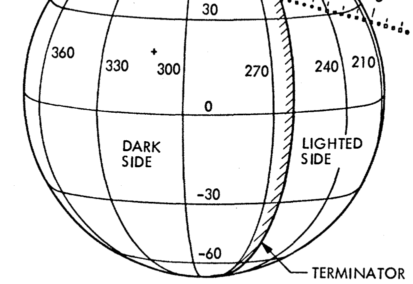

Fig. 1 Swath of the radiometer's field of view across the disk of Venus. The times indicated by the trace are given in minutes before the closest approach of Mariner 10.

The intensity of 45-μm radiation, $I_{45}(\mu)$, is shown in Fig. 2 as a function of the planetocentric longitude together with the deviation from a limb darkening law of the form

$$I_{45}(\mu) = I_{45}(1.0)\ (0.76 + 0.24\,\mu) \qquad (1)$$

where μ is the cosine of the emission angle and I_{45} (1.0) is the intensity when $\mu = 1$. Because the data have not been corrected for out-of-field stray radiation and the trajectory geometry is still preliminary, only emission angles