Pioneer Venus Mission Plan for Atmospheric Probes and an Orbiter

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The 1978 mission concept is described for a spin-stabilized Pioneer spacecraft which is being designed to function as a Venus orbiter and as a probe carrier on a second flight. The same "Bus" spacecraft will be the basic vehicle for both flights. In its orbiter configuration, the Bus will weigh about 500 kg (1100 lb) at launch and will serve as a platform from which the upper atmosphere, its interaction with the solar wind, and the surface topography of Venus will be examined. The orbiter's lifetime will extend over a complete sidereal day and solar year of Venus. In its probe-carrier configuration, the Bus will weigh about 820 kg (1800 lb), including Probes, at launch and will deliver one large and three Small Probes to enter the atmosphere of Venus and to directly measure its characteristics. Program approval is expected in fiscal year 1975. Requirements for cost effectiveness and firm adherence to early cost projections are emphatic program guidelines which affect every major element of the mission plan and conceptual design.

Introduction

VENUS is thought by some to be accelerated in its planetary evolution in comparison with the Earth; others believe it to be more primitive. Observations of the cloud-shrouded planet from the Russian probes, the Mariners 2 and 5 fly-bys, and Earth-bound instruments indicate a high surface temperature, intense pressure, a carbon dioxide atmosphere, a high velocity upper atmosphere circulation, a negligible magnetic field, and deep solar energy penetration. Mariner 10 tends to confirm a four Earth-day global atmospheric circulation. Distinct cloud stratification was suggested by the radio occultation signature of Mariner 5. Radar imaging from Earth indicates a relatively smooth solid surface with possible mountainous areas.

Even with our present information, we lack definitive detail about most Venus phenomena. We do not know the precise dynamics of the atmosphere, its composition, or the chemical and physical structure of the clouds. Fundamental questions of energy balance are still open.

The purpose of the Pioneer Venus Project is to make cost-effective extensions of our present knowledge of Venus. Primary objectives are to obtain global atmospheric measurements which might help differentiate among theories of planetary evolution and to do so at a predictable and minimum cost.

The project will consist of two flight spacecraft, one to penetrate into the Venusian atmosphere, and the second to orbit the planet for a Venusian sidereal day (243 Earth-days), which encompasses a Venusian year (225 Earth-days).

History and Status

Early in 1972, the Pioneer Venus Study was transferred to the NASA Ames Research Center after completion of the "Phase A" feasibility study[1] by Goddard Space Flight Center (GSFC), under the designation of Planetary Explorer. The efforts of the GSFC go back at least to 1968 when ideas for a low-cost, spin-stabilized, Delta-launched spacecraft to deliver probes and orbiters to Venus were being organized and scientific payloads were being studied.[2,3]

Contracts for competitive design studies were let in 1972 by Ames. A Science Steering Group (SSG) began deliberations at that same time to establish priorities for measurements to be made at Venus.[4] Based upon the advice of this group, an Announcement for Flight Opportunity (AFO) was issued and a tentative science payload was selected for the Multiprobe Mission (see Table 1). The Announcement of Flight Opportunity for the Orbiter Mission was issued in July 1973; selection of those experiments will be made in the Spring of 1974.

The program is included in NASA's budget request to Congress for FY 1975. Subject to approval by Congress, the winning contractor, Hughes Aircraft Co., will begin the detailed design and fabrication phases of the program, leading to launches in 1978.

Mission Objectives

Investigation of the Venusian atmosphere—its composition, circulation, cloud structure, thermodynamics, and interaction with solar emissions—is the primary scientific objective of the Probe and Orbiter Missions.

Probe Missions

Three identical "Small Probes" and a single "Large Probe" will be delivered to Venus by a "Bus" spacecraft. The Probes will be designed to return data down to within the lowest atmosphere scale height above the surface, but they will not be designed to function after impact. The Bus, which will also carry scientific instruments, will return high-altitude atmospheric data before its destruction during entry. The total weight of the scientific instruments on the Bus and within the four Probes will be approximately 48 kg (105 lb).

Small Probes

Each Small Probe will carry a temperature gage, pressure gage, and accelerometer to determine the physical structure of the atmosphere at each entry location. Each will also carry a nephelometer, or optical cloud detector, to profile cloud densities during descent; a broad-band flux detector to measure thermal and light energy distribution within the atmosphere; and a stable

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Table 1 Pioneer Venus probe mission science team

Probe Bus payload	Investigator, Institution
Neutral mass spectrometer	Von Zahn, Univ. of Bonn, Germany
Ion mass spectrometer	Taylor, NASA/GSFC
Retarding potential analyzer	Knudsen, Lockheed, Palo Alto
Electron temperature probe	Nagy, Univ. of Michigan
Ultraviolet spectrometer	Stewart, Univ. of Colorado
Large Probe payload	
Atmosphere temperature, pressure, and structure	Seiff, NASA/ARC
Neutral mass spectrometer	Spencer, NASA/GSFC
Gas chromatrograph	Oyama, NASA/ARC
Solar radiometer	Tomaski, Univ. of Arizona
Cloud partice size spectrometer	Knollenbergy, Univ. of Chicago
Spin scan photometer	Weinman, Univ. of Wisconsin
Nephelometer	Blamont, CNES, France
Small Probe payload	
Atmosphere structure	Seiff, NASA/ARC
Nephelometer	Blamont, CNES, France
Net flux radiometer	Suomi, Univ. of Wisconsin
Radio science team	
Differential very long baseline interferometry (DLBI)	Pettengill, MIT
Radio propagation	Croft, Stanford Univ.
Turbulence	Woo, JPL
	Kliore, JPL
Theorists	
	Goody, Harvard Univ.
	Hunten, Kitt Peak National Observatory
	Donahue, Univ. of Pittsburgh
	Pollack, NASA/ARC
	Bauer, NASA/ARC

oscillator controlling the r-f signal to facilitate measurement of the wind profiles at each location.

Large Probe

The Large Probe will contribute a fourth set of the same measurements made by the Small Probes. In addition, it will carry a neutral mass spectrometer and a gas chromatograph to determine the chemical composition of the lower atmosphere; a cloud particle size spectrometer to help identify particulate matter; and two radiometers to measure thermal flux and solar energy deposition as functions of altitude.

Bus

The Bus will carry the entry Probes to Venus and will carry independent scientific instruments to identify and measure molecular and ionic constituents of the atmosphere above 130 km altitude. After dispersing its entry probes, the Bus will be retarded in its approach to Venus, to enter later than the Probes, so that the Bus transponder can serve as a frequency reference for interferometric tracking of the wind-driven Probe descents.

Before the Bus entry communications blackout, a neutral mass spectrometer will analyze atmospheric gases. An ion mass spectrometer will analyze atmosphere ions, an electron temperature probe and retarding potential analyzer will measure ion and electron temperatures and distributions, and an ultraviolet spectrometer will map Lyman-Alpha corona and produce altitude profiles of airglow emission frequencies.

Orbiter Mission

Based upon scientific studies,[4,5] the Orbiter is planned to be injected into an orbit with a high inclination to the Venusian orbit plane and with a periapsis maintained between about 200 and 400 km altitude. The spacecraft will be designed to operate for at least a Venus sidereal day (243 Earth-days), so that a band of observations will encircle the planet and the upper atmosphere will be sampled at all phases of the light-dark cycle.

The generally desired scientific measurements and some candidate instruments for the Orbiter mission are as follows.

a) Interaction of the solar wind with the ionosphere of Venus. A magnetometer will determine if a magnetic field exists to affect this interaction. A plasma analyzer will investigate the sharply bounded ionopause and the extensive plasma tail discovered by Mariner 5, and electron and ion temperature probes will characterize the ionosphere.

b) Composition, photochemistry, and airglow of the outer atmosphere and ionosphere. The Orbiter's periapsis will be periodically dropped as low as practicable to allow neutral and ion mass spectrometers to help define the composition of the upper atmosphere and ionosphere. Sensors will measure photoelectrons to the lowest practical altitude to determine if they have a role in distributing heat about the globe. Verticle profiles of electron densities and ion temperatures will improve upper-atmosphere theoretical models.

c) Thermal and density structures of the lower atmosphere. An ultraviolet spectroscope will clarify indications, from Earth and Mariner 10, of markings in the clouds of Venus. It will investigate the corona seen by Mariner 5. An infrared scanner will be employed to infer the CO_2 temperature as a function of pressure within the atmosphere, to search for the possible existence of water vapor and to detect thin clouds if they exist in outer layers of the atmosphere.

d) Topography, radar reflectivity, and roughness of the solid surface. A radar altimeter will make altimetry measurements along the widest practical swath of the planet's surface by sampling along the suborbital track. Reflectivity characteristics will contribute clues as to the surface structure and perhaps the evolution of Venus.

The orbiter will contribute two types of scientific measurements in addition to those made by the above instruments. First, its S-band telemetry transponder will be complemented with an X-band transmitter to provide dual-frequency occultation measurements during 20–40 passes behind Venus. By these occultations, the spacecraft will help define Venus' atmospheric density, ionization, and stratification. Second, the Orbiter will provide measurements of the mass characteristics of Venus by means of Earth-based orbital tracking data.

Mission Design

Both the Probe and Orbiter missions are planned for launch in 1978. Insofar as is practical, all spacecraft subsystems will use existing technology, i.e., preference will be given to mechanisms and components which have been flown before or for which a minimum of qualification is required. Experiments also will be selected with emphasis on historical flight confidence. A major design objective is to develop the Probe Bus, Probes, and the Orbiter with a maximum of commonality in subsystems, assemblies and components.

The Probe Bus features a spinning cylindrical body with solar cells and the three Small Probes mounted on its periphery. The Large Probe will be mounted at the end of the cylindrical structure, opposite the launch vehicle attachment. The Bus will provide the structure, power, attitude control, communications, and propulsion subsystems to support the Probes until their release.

Approximate gross weights for each of the Small Probes will be 57 kg (125 lb), and for the Large Probe, 227 kg (500 lb). The probes, when released, will be autonomous and will transmit telemetry directly to Earth, with their battery power and internal heat capacitances conserved until just prior to Venus entry. Probe

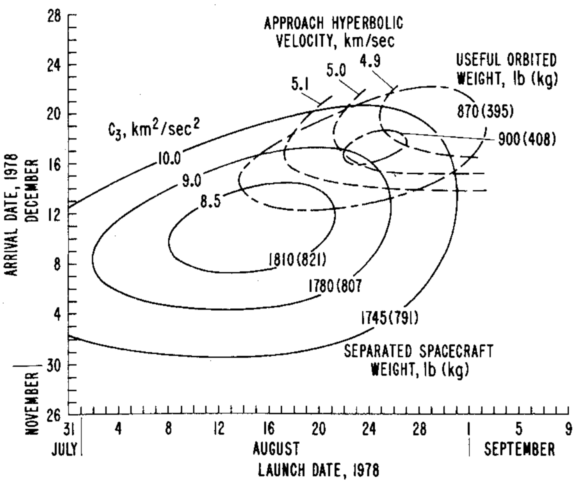


Fig. 1 Earth-to-Venus launch/arrival capabilities of Atlas/Centaur D-1AR for the Type I opportunity.

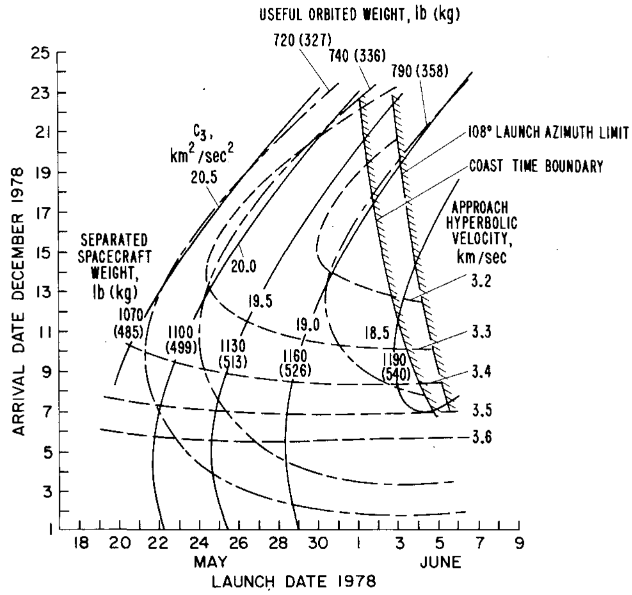


Fig. 2 Earth-to-Venus launch/arrival capabilities of Atlas/Centaur D-1AR for the Type II opportunity.

trajectories, spin rates, and attitudes will be determined by the Bus conditions at their release.

The Orbiter design will replace the Large Probe assembly on the Bus with a despun antenna structure; it will locate a solid retrorocket within the cylindrical body and will provide shelf space for scientific instruments in place of the Small Probes. Except for these changes, the subsystems will be largely identical in the Orbiter and in the Bus.

Launch Vehicle

The Atlas/Centaur D-1AR vehicle has been selected for both missions. The choice was made after the original studies based upon the Thor/Delta had identified a full load of instruments ambitiously packed into the Probes and Orbiter. Spacecraft cost savings substantially offsetting the difference in launch vehicle costs have been estimated, especially in the areas of aeroshell design, Probe insulation, structural design of the Bus and Orbiter, and power.

Launch/Arrival Date Tradeoffs

The launch of the Probe mission is planned for the Type I¶ trajectory opportunity in 1978. The most favorable launch opportunity will be in Aug., as shown in Fig. 1, and will allow the separated spacecraft weight to be as large as 820 kg (1800 lb) for a 10-day launch period. The launch of the Orbiter mission is planned for the 1978 Type II¶ opportunity, which will occur in May, as shown in Fig. 2. This opportunity allows the separated spacecraft weight to be as large as 500 kg (1100 lb) in spite of several mission constraints: launch vehicle coast time and launch azimuth limits preclude launches after the first few days of June; the useful in-orbit weight depends on the approach hyperbolic velocity as well as launch energy (C_3); the use of a fixed-burn (solid) orbit-insertion motor requires a near-constant planet approach velocity for all 10 days of the launch period; and for mission operations considerations, the Venus arrivals of the Probe and Orbiter spacecraft are to be separated by at least five days. As presently planned, both missions would arrive in Dec. 1978, with the Orbiter preceding the Probes.

As shown in Fig. 1, a moderate Orbiter weight advantage could result from flying the mission on a Type I trajectory. However, this advantage is outweighed by the disadvantages of reduced Probe mission weight, necessary to separate the two launch periods for launch pad turnaround, and of the scientifically less desirable orbits which result from the Type I transfer.

¶ Type I trajectories are those for which the Sun-centered transfer angle is less than 180°. Type II trajectories are those for which the transfer angle is between 180° and 360°.

Tracking and Data

Figure 3 shows the relative positions of Earth, Venus, and the spacecraft with a Type II Orbiter launch and a Type I Probe launch. As seen from Earth, the two spacecraft will be in the same sector of the sky near arrival.

The communications range to Earth from the probes at Entry is about 65,000,000 km, just over 1.5 times the minimum Venus/Earth distance. Orbiter in-orbit communications will begin at a similar range and increase to 257,000,000 km. The basic Orbiter mission will be completed only about two weeks before the superior conjunction of Venus with Earth.

Navigation for both interplanetary flights (and for orbit control) will be based upon coherent two-way Doppler only. Ranging was found unnecessary to achieve the required accuracy. Two near-Earth maneuvers are anticipated to correct launch errors of each flight, and a third maneuver 30 days before Venus arrival will probably be necessary to adjust the spacecraft delivery, considering uncertainties of solar pressure modeling prior to that time.

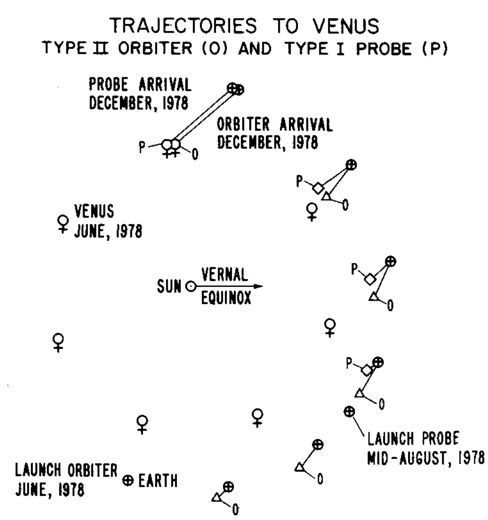


Fig. 3 1978 Pioneer Venus interplanetary trajectories; Orbiter—Type II transfer; Probes—Type I transfer.

The Large Probe and Bus will carry coherent transponders to provide two-way Doppler tracking. The Small Probes will have stable oscillator-controlled transmitters to provide precision one-way Doppler tracking during descent through Venus' atmosphere. Deep Space Station overlap tracking with 64-m antennas will be essential during Probe entries. Maximum overlap between Goldstone (Calif.) and Canberra (Australia) sites will be used so that differential very long baseline interferometry (DLBI) analysis of the descent trajectories can be made to construct wind profiles experienced by each entry Probe. Predetection recording will be made of the five simultaneous signals from the three Small Probes, Large Probe, and Bus. Multiple use of two or three adjacent telemetry carrier channels is envisioned for practical ground recording bandwidth requirements. Also, this close grouping of frequencies will improve the DLBI analyses. Probe data rates and buffer storage will be varied during descent so as to optimize scientific data return.

Orbiter scientific data is primarily collected at low altitudes during periapsis passages, some of which are in occultation from Earth. Spacecraft onboard storage of the order of 10^6 bits will be filled during each periapsis pass for replay later in the orbit to DSN ground stations. At the longest communications ranges from Venus, the mission design is expected to require at least one daily pass of a 26-m DSN station.

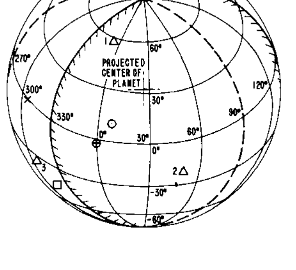
Probe Deployment

Scientific guidelines for targeting of Probes and the Bus were established by the Science Steering Group[4] and will be refined by the recommendations of the experimenters selected for the mission. In summary, the targeting requirements are to: 1) locate the Large Probe near the equator at least 20° into daylight from the terminator; 2) place two of the Small Probes at least 30° apart in absolute value of latitude; 3) place two of the four Probes at least 90° apart in longitude; 4) enter the Bus in daylight with a low flight path angle which allows the most time for data collection between 1000 km and 100 km altitude; and 5) delay Bus entry such that its transponder can serve as a frequency reference for DLBI during descent of the four entry Probes to the surface. These requirements were structured as a practical set of targeting criteria compatible with the general design approach conceived for the project.

Capabilities

The possible Probe targets at Venus are established by the planet-approach asymptotic velocity vector, and these accessible regions of the planet for the 1978 Type I opportunity are shown in Fig. 4. In that figure, the accessible coordinates are shown projected to an imaginary plane, called the "target plane," centered at Venus and perpendicular to the approach asymptote direction. Targeting possibilities become easy to visualize in the target-plane projection. This projection absorbs the trajectory-

B-PLANE PROJECTION OF VENUS FOR PROBE TARGETING
1978 TYPE I



○ S.P.'S PRE-RELEASE TARGET
△ S.P.-1, 2, 3
□ BUS ENTRY
⊕ SUB EARTH POINT
× LARGE PROBE
TERMINATOR
— — LIMB OF EARTH VIEW

ENTRY CONDITIONS

	BUS	S.P. 1, deg	S.P. 2, deg	S.P. 3, deg	LP, deg
DESCENT COMMUNICATION ANGLE	(n.a.)	60°	52°	58°	51°
ENTRY FLIGHT PATH ANGLE	-11°	-65°	-48°	-19°	-33°
ENTRY ANGLE OF ATTACK	*	15°	14°	20°	0°

* CONTROLLABLE

Fig. 4 Representative Probe targeting in target-plane projection; 1978 Type I transfer.

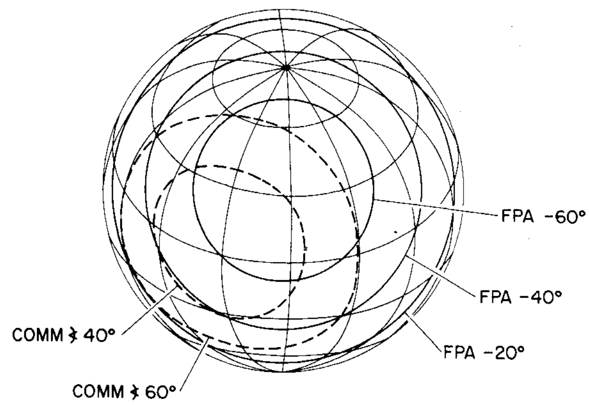


Fig. 5 Contours of constant Probe entry flight path angle (FPA) and postentry communications angle (COMM); 1978 Type I transfer.

bending effect of the planet's gravitational field, so that planning for Probe targeting can be done with linear concepts. In order to have a Probe enter at certain coordinates on Venus, the Probe's approach asymptote simply has to be deflected to the point on the target plane where those coordinates are indicated.

Since the Large Probe will be the first to be released, it will be directly targeted by the launch vehicle and the three spacecraft midcourse maneuvers. Its targeting will account for the impulse produced by the Large Probe separation springs.

Small Probe targeting will be accomplished as follows. After the Large Probe release, the Probe Bus will fire thrusters to retarget its approach asymptote. The Bus will then be reoriented to the Small Probe release attitude, and its spin rate increased. The three Small Probes will be released simultaneously and will be distributed in the target plane by their tangential velocities at release. After releasing the Large and Small Probes, the Bus will be maneuvered and will be retarded so as to arrive at its target point at the planet later than the Probes. Representative target points which satsify the basic scientific requirements are shown in Fig. 4. They also appear to be compatible with the design constraints outlined below.

Design Implications

Release of Probes from the spinning Bus establishes their spin rate and orientation during their individual solo flights to Venus and also determines their angles of attack upon entry.

The Bus attitude at the releases of the Probes will be constrained because of Probe solar aspect angle limits and entry angle of attack limits. The Sun must not be allowed to shine on the aft surface of the Probes during their flights to Venus. Also, the entry angle of attack must be small enough to ensure that the Probes will be aerodynamically stable. The target points in Fig. 4 can be approached with acceptable solar aspect angles and with entry angles of attack less than 20°.

Telemetry antenna patterns must allow direct transmission to Earth from the Probes, both in the Probes' cruise orientations before entry and in their local vertical orientations during descent through the atmosphere of Venus. A limitation on the descent communications angle is a special targeting constraint. Common antenna designs are preferred for economy and interchangeability within the Small Probes, and they are likely to provide antenna patterns with about 60° half-cone beam widths from the spin axis. Communications angles and flight path angles are tabulated for the set of Probe entry locations illustrated in Fig. 4, and contours of these angles for the 1978 mission are indicated as a function of entry location in Fig. 5.

Descent Profiles

Figure 6 indicates the relative rates of descent through the atmosphere for the Large Probe and the three identical Small Probes. A parachute will be used to retard the Large Probe descent through the upper clouds to allow detailed measurements

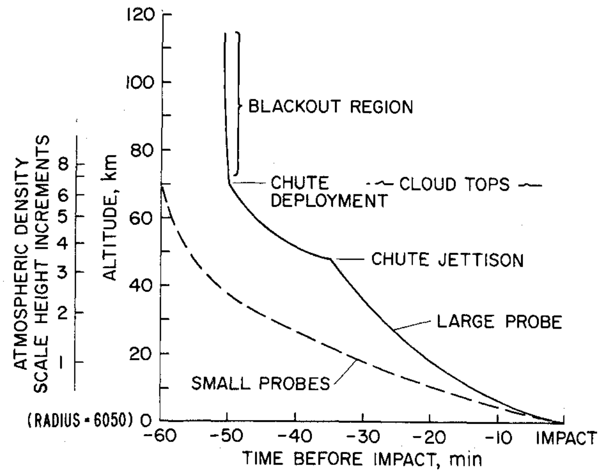


Fig. 6 Pioneer Venus Probe descent profiles.

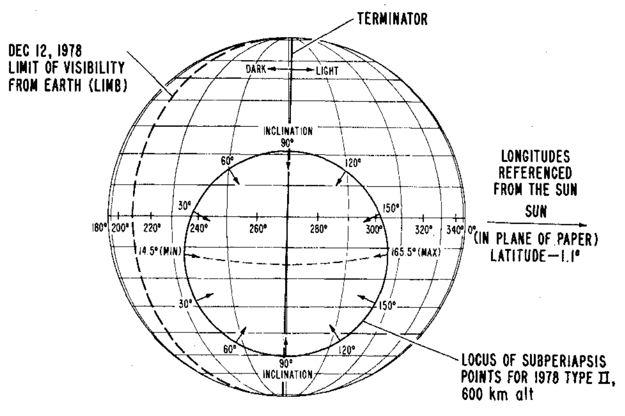


Fig. 8 Venus Orbiter injection locations and orbit inclinations; 1978 Type II transfer.

in this important region. An aeroshell will protect the Large Probe only through supersonic flight, after which it will be jettisoned. The Small Probes will keep their aeroshells to the surface.

Bus measurements during entry will be most important below 1000 km. Experimenters require the angle of attack of the Bus spin axis to be 10° or less. As previously mentioned, a low flight path angle is necessary to allow adequate time for data collection. Bus antenna design and the required high data rate through the final minutes before burn-up will dictate reasonably small Earth-aspect angles for the Bus approaching entry. The representative targeting for the Bus, shown in Fig. 4, is profiled in Fig. 7. It will probably be essential to keep Bus targeting near the plane containing the Venus-centered asymptote and the sub-earth point to satisfy the objectives and constraints noted.

Establishing the Orbit

Scientific guidelines for the choice of orbit are complex and perhaps less clearly resolved than for probe targeting. One parameter is most clear: inclination to the ecliptic must be high, in the range of 60°–120°, and possibly polar. The altitude of periapsis is also required to be as low as conservatively practical, with 200 km the generally agreed upon design goal. Latitude of periapsis is preferred in the "midrange" of 25°–45° in either hemisphere. But, as will be shown, the choice of latitude of periapsis will be greatly constrained by other considerations and may not lie in the preferred range.

The apoapsis altitude should be as low as possible to allow the orbit to be most sensitive to gravity field harmonics. The amount of retropropellant which can be carried, however, will limit the apoapsis to the order of 10 Venus radii. For these reasons, and to simplify and minimize ground tracking station schedules, an orbital period of 24 hr is planned.

Capabilities

For a given approach velocity vector, a circular locus of the most efficient orbit injection points can be defined about the protrusion point of the approach vector on the opposite surface of the planet. Such a locus for the 1978 Type II mission is plotted in Fig. 8. The orbited mass capability defined in Fig. 2 can be achieved at any point on this circle with the same solid retrorocket, resulting in an orbit inclination as noted. Injection altitude will nominally be targeted at 400 to 600 km to protect against planetary impact due to navigation error.

Design Implications

Selection of orbit inclination and latitude of periapsis (which are not firmly selected parameters as of this writing) affects a number of design considerations. Mountings and scanning angles relative to the spin axis for the individual scientific instruments must be chosen to be compatible with orbit inclination and latitude of periapsis. The stipulations mentioned, i.e., near polar inclination and midlatitude periapsis, generally satisfy the planned experiments. Optimization within those bounds, if and as allowed by the spacecraft design, will require detailed tradeoff assessments. Figure 9 indicates how durations of solar eclipses and Earth occultations vary in the two polar orbits possible with a Type II interplanetary trajectory.

Orbit injection will require the spin-stabilized retrorocket axis to be pointed along the initial periapse velocity vector sufficiently before injection to verify and, if necessary, adjust the orientation.

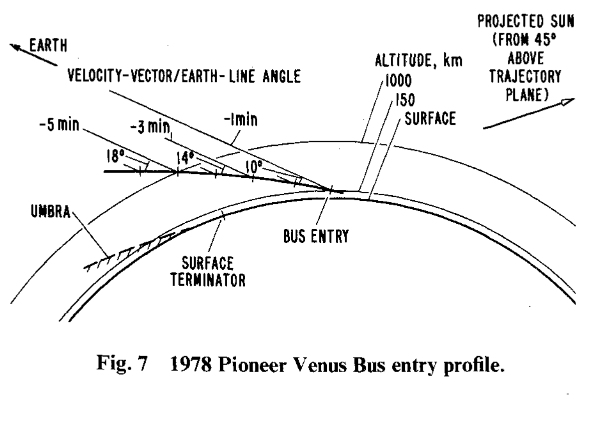


Fig. 7 1978 Pioneer Venus Bus entry profile.

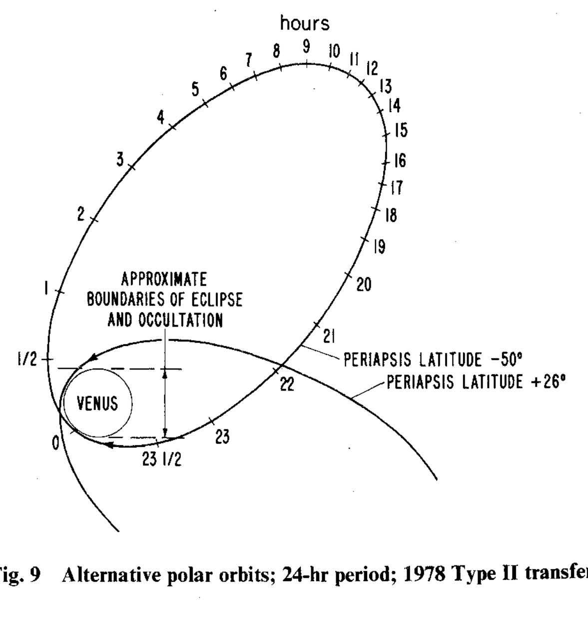


Fig. 9 Alternative polar orbits; 24-hr period; 1978 Type II transfer.

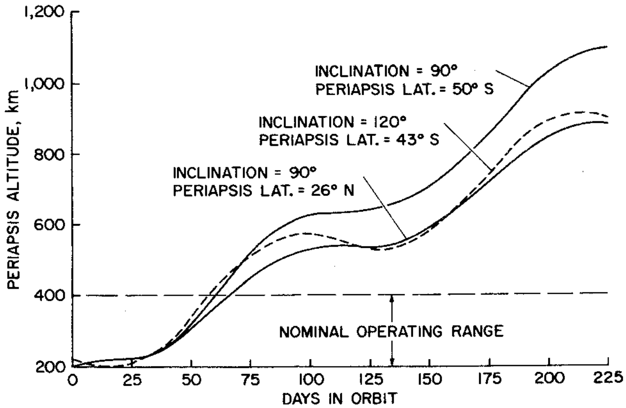


Fig. 10 Trends in Venus Orbiter periapsis altitude due to solar gravitation; 24-hr period; 1978 Type II transfer.

During such a period, the solar aspect angle must be accommodated thermally and electrically (i.e., with sufficient power in storage or from solar cells), the attitude control system must define orientation within about 1°, and telemetry data must be receivable.

In-orbit maneuvers will be necessary to adjust velocity magnitudes at periapsis and at apoapsis, both for initial orbit correction and to maintain periapsis altitude as low as required for scientific effectiveness. The predominant disturbance to the orbit will be the third-body gravitational effect of the Sun on the periapsis altitude. This effect on an uncontrolled, highly inclined Venus orbit is shown in Fig. 10, for the duration of the 1978 Type II mission. The third-body effect can be controlled by ΔV maneuvers, and the stipulated requirement is to maintain periapsis altitude between 200 and 400 km. A closer control will be desired, if propellant is available. A 20–40 km limit in altitude fluctuation would keep the deepest measurements within one density scale height of the same altitude. Other disturbances to the orbit are expected to be small. Solar gravity has a minimal effect on the other orbit parameters, atmospheric drag is insignificant above 200 km, and the near-spherical gravity field of Venus is expected to cause only small perturbations.

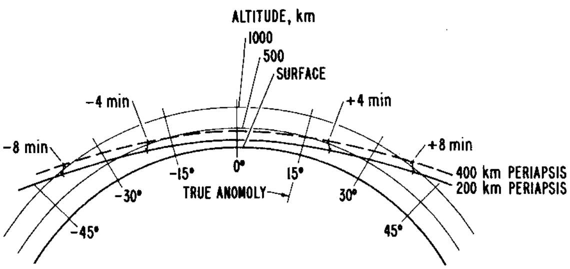


Fig. 11 Venus Orbiter altitude, true anomaly, and time periapsis; 24-hr period.

Area of Observation

Figure 11 shows coverage below 1000 km altitude, extending 35°–40° true anomaly on both sides of periapsis for the minimum altitudes of 400 and 200 km, respectively. A 1000 km altitude is the probable limit of effectiveness of a radar altimeter and is near the expected useful range of aeronomy experiments. The latitude band of intense scientific investigation of Venus, then, will be defined by the selected orbit inclination and latitude of periapsis.

The latitudes and degrees of sunlighting of the regions over which occultations of the r-f signal will occur are dictated by the choice of orbit. Generally, for high inclination orbits, there will be an initial "season" of some 40 days of occultations at various latitudes when the spacecraft is close to the atmosphere. The repetitive nature of occultations with the Orbiter, and the unavoidable spread in longitude and latitude of atmospheric radio paths that can be sampled, make the experiment attractive without particularly influencing the selection of the orbit.

Operational Sequence

The approach to Venus with the Orbiter will entail careful alignment of the spacecraft for retro-rocket firing within design constraints. Some type of confidence exercise will be necessary in advance of the actual firing, since heavy reliance upon ground computations and control is visualized for a low-cost spacecraft design.

One DSN station pass per day will suffice for typical minimum requirements. The schedules will consist of periods of data memory readout, attitude adjustment and occasional orbit trims. Additional tracking support schedules will be dependent upon requirements for control of altitude.

Conclusion

The Pioneer Venus Probe and Orbiter missions planned for 1978 are designed to satisfy scientific requirements for productive improvement in our understanding of Venus and its environment. The flexibility in mission design remaining at this time has been identified for adaptive use in economizing hardware design and optimizing scientific observation.

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