# The Pioneer Venus Spacecraft Program

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**The Pioneer Venus program consists of two spacecraft: an orbiter and a multiprobe. Both will arrive at Venus in early December 1978. The orbiter will collect data on the upper atmosphere and fields and particles and will sense the clouds and surface remotely from a 75-deg inclined orbit. The multiprobe consists of a bus, three small probes, and a large probe. All five objects will enter the Venus atmosphere and will transmit data on its characteristics directly to Earth while descending to the surface. The entire mission is expected to increase our knowledge of the planet Venus substantially, especially its atmosphere.**

## Introduction

THE Pioneer Venus program evolved from recommendations made by the Space Science Board of the National Academy of Sciences during the late 1960's and early 1970's. In a series of studies, the Space Science Board concluded that there was a need for relatively low-cost orbiters and landers to explore the planet Venus. Despite being Earth's closest planetary neighbor, relatively little was known about the planet Venus, especially its lower atmosphere. What was known (that the planet is covered with clouds; the atmosphere is principally $CO_2$ with traces of other elements, including sulphuric acid; the surface pressure is 95 Earth atm; and the surface temperature is 493°C) raised many important scientific questions. The answers to these questions should enhance our knowledge of our own atmosphere and weather here on Earth. It was decided that the exploration of Venus should proceed with two complementary missions: a multiprobe to enter the Venus atmosphere and an orbiter.

The objectives of the multiprobe mission are to determine 1) the composition of the clouds, 2) the composition and structure of the atmosphere from the surface to high altitude, and 3) the general configuration of the atmosphere. The objectives of the orbiter mission are to determine 1) the detailed structure of the upper atmosphere and ionosphere by in situ measurements, 2) the interaction of the solar wind with the Venus ionosphere and with the small magnetic fields in the vicinity of the planet, 3) the characteristics of the atmosphere and surface of Venus on a planetary scale by remote sensing experiments, 4) the planet's gravitational field harmonics from perturbations from the spacecraft's orbit around Venus, and 5) gamma ray burst density for the solar system interferometer network.

In addition, consistent with the Space Science Board's initial recommendations, emphasis is to be placed on accomplishing the Pioneer Venus spacecraft mission at relatively low cost. This paper describes the current spacecraft configuration and mission plans as of December 1976. It also touches briefly on the science payload.

## Multiprobe Mission

### Multiprobe Spacecraft Description

The multiprobe consists of a bus, large probe, and three small probes, each of which includes a payload of scientific instruments. The mission of the multiprobe is to target the four probes for entry into the descent through the Venus atmosphere. The bus is destroyed during atmospheric entry after its two scientific instruments have sampled the upper atmosphere of Venus.

The multiprobe is spin-stabilized, and its spin axis will be normal to the ecliptic except when required to be otherwise by the mission. The spacecraft will be launched by an Atlas SLV-3D/Centaur D-1AR launch vehicle from CCAFS (Cape Canaveral Air Force Station), Fla. Command, telemetry, and tracking will utilize the three Deep Space Network (DSN) stations in California, Australia, and Spain. The mission control center will be located at Ames Research Center, Moffett Field, Calif.

The multiprobe is shown in an exploded view in Fig. 1. The basic elements of the structure are a thrust tube that provides the load path for transmitting acceleration loads into the spacecraft, a 248-cm-diam cylindrical substrate 122 cm in length for mounting the solar cell array, and the probe support structures. The large probe is supported on the spacecraft centerline by an inverted conical structure and is separated with a small differential velocity provided by springs. The three small probes each are supported by an aluminum honeycomb panel and struts. They are retained by spring-loaded circular clamps. Upon pyrotechnic release of the clamps, the probes are separated centrifugally from the bus. A single-piece attach fitting that remains with the

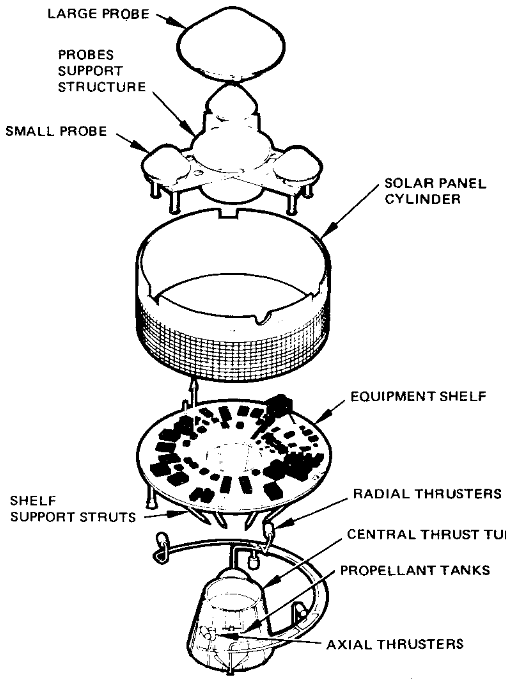


**Fig. 1 Multiprobe exploded view.**

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Centaur at spacecraft separation provides the mechanical and structure interfaces with the launch vehicle. The structure is designed to support a combined spacecraft and attach fitting weight of 921 kg.

Thermal control of the bus is provided by 11 louvers mounted to the underside of the shelf, various heaters on elements of the propulsion subsystem and the underside of the shelf, aluminized Kapton thermal blankets, and appropriate thermal finishes and paints. A summary of the characteristics of the bus spacecraft subsystems is given in Table 1. The bus spacecraft must also provide power, commands, and telemetry for checkout of the probes prior to their release. Probe checkout data are biphase-modulated on the probe subcarrier and transmitted across the probe/bus interface, where they are modulated on the rf carrier along with the bus subcarrier. The bus instrument payload consists of two instruments weighing 11 kg and consuming 30 W of electrical power. The principal investigator and the scientific objective of these two instruments are summarized in Table 2.

### Large-Probe Description

The large probe is to be targeted to a point on the daylight side of Venus, 18 deg from the terminator and within ±10 deg lat of the subsolar trace. This requires an entry speed of 11.6 km/sec, a nominal entry angle of −33.8 deg, and a communication angle of 52 deg from the local vertical during descent. To provide targeting flexibility, the large probe is designed for entry angles of −25 to −45 deg. The maximum deceleration force during entry could be as high as 400 *g*, depending on the entry angle.

Parachute deployment occurs at 67 km alt, followed by an 18-min descent to 46 km, where the parachute is jettisioned. The stabilized freefall to the surface of Venus requires about 38 min. The probe is not required to survive impact but is designed to withstand the absolute pressure of 9653 kPa and 493°C conditions at the surface. The acceleration, temperature, and pressure environments are unique to the Pioneer Venus mission and present challenging technical problems for design and test.

**Table 1 Bus and orbiter subsystem characteristics**

| | Multiprobe/Bus | Orbiter |
|---|---|---|
| Power | Solar array ($6m^2$): 228 W at Earth<br>Batteries: 2 7.5 A-hr, Ni-Cd<br>Electronics: 28 V ±10% | ($7.4\ m^2$), 325 W at Venus<br>Same<br>Same |
| Control | Spin stabilized: 5 to 65 rpm<br>Sun sensors<br>Star sensor: 24 stars in 24° FOV<br>Spin reference signals<br>Ground attitude determination and control | 15 to 65 rpm<br>Same<br>Same<br><br>Same<br>Same |
| Propulsion | 6 4.4 N axial and radial thrusters<br>2 tanks, 32 kg hydrazine | 7 thrusters<br>Same<br>Orbit insertion motor: 1061 m/sec |
| Command | PCM/FSK/PM at 4 bps<br>48 bit command words<br>384 pulse commands<br>12 quantitative commands<br>128 stored commands | Same<br>Same<br>Same<br>Same<br>Same |
| Telemetry | Convolutional encoded, PCM/PSK/PM<br>8 to 2048 bps<br>8 bit words<br>64 word frame<br>16 formats<br>253 channels | Same<br>Same<br>Same<br>Same<br>Same<br>Same<br>1.04 m bit core storage |
| Communication | S-band transponder<br>10 or 20 W power amplifier<br>Medium gain horn antenna - aft<br>Omni antenna - forward and aft | Same<br>Same<br>X-band transmitter (750 mW)<br>Same<br>Mechanically despun parabolic antenna (109 cm)<br>S/X-band feed<br>Despun backup antenna |

The large probe consists of a pressure vessel module and a deceleration module (shown in exploded view in Fig. 2), with a total mass of 317 kg. The deceleration module decelerates the probe and provides thermal protection during atmospheric entry. The deceleration module consists of a 45-deg blunt cone aeroshell with a 142-cm diam and 36-cm nose radius. A carbon phenolic heatshield is bonded to an aluminum ring-stiffened monocoque structure. An ESM-coated fiberglass aft cover provides thermal protection during entry for the base of the probe. A 5-m-diam Dacron conical-ribbon main parachute is deployed by a 0.8-m-diam pilot chute ejected by a mortar. The parachute system extracts the pressure vessel module from the deceleration module. The

**Table 2 Multiprobe scientific payload**

| Instrument/Principal Investigator | Measurement Objectives |
|---|---|
| BUS | |
| Neutral Mass Spectrometer<br>U. von Zahn, U. of Bonn | Composition and concentrations of neutral particles in the upper atmosphere (2,000 km − 140 km) |
| Ion Mass Spectrometer<br>H. Taylor, GSFC | Ionospheric composition and concentrations of charged particles ( ≤ 4,000 km) |
| LARGE PROBE | |
| Neutral Mass Spectrometer<br>J. Hoffman<br>University of Texas | Composition of the lower atmosphere to measure the number densities of various neutral atmospheric constituents and their altitude dependence |
| Gas Chromatograph<br>Vance Oyama<br>Ames Research Center | Determine the presence of various gases in the lower atmosphere by measuring their retention times in gas chromatograph columns |
| Comparative Atmosphere Structure<br>A. Seiff<br>Ames Research Center | |
| Temperature | Determine the temperature profile from 70 km to the surface |
| Pressure | Determine the static pressure of the atmosphere from 70 km to the surface |
| Accelerometers | Atmospheric density above 70 km. Information on winds and turbulence below 70 km. |
| Solar Flux Radiometer<br>M. Tomasko<br>University of Arizona | Determine the rate at which solar energy is deposited in various layers of the atmosphere, establish the basic thermal heat budget and dynamic driving force for the atmosphere |
| Infrared Radiometer<br>Robert Boese<br>Ames Research Center | Thermal flux as a function of altitude, location, and composition of clouds, water vapor abundance |
| Cloud Particle Size Spectrometer<br>Robert Knollenberg<br>Particle Measuring Systems | Relative number, distribution, and sizes of particles in the lower atmosphere |
| Nephelometer<br>B. Ragent<br>Ames Research Center | Determine the presence and vertical structure of clouds |
| Transponder for Doppler and DVLBI (Differential Very Long Baseline Interferometry)<br>G. Pettengill, MIT | Probe descent profile and horizontal winds |
| SMALL PROBE | |
| Comparative Atmosphere Structure<br>A. Seiff<br>Ames Research Center | |
| Temperature | Determine the temperature profile from 70 km to the surface |
| Pressure | Determine the static pressure of the atmosphere from 70 km to the surface |
| Accelerometer | Atmospheric density above 70 km. Information on winds and turbulence below 70 km |
| Nephelometer<br>B. Ragent<br>Ames Research Center | Determine the presence and vertical structure of clouds |
| Net Flux Radiometer<br>V. Suomi<br>University of Wisconsin | Determine the net balance of energy — solar absorption and radiative cooling |
| Stable Oscillator for Doppler and DVLBI (Differential Very Long Baseline Interferometry)<br>G. Pettengill<br>Massachusetts Institute of Technology | Determine probe descent profile and horizontal winds |

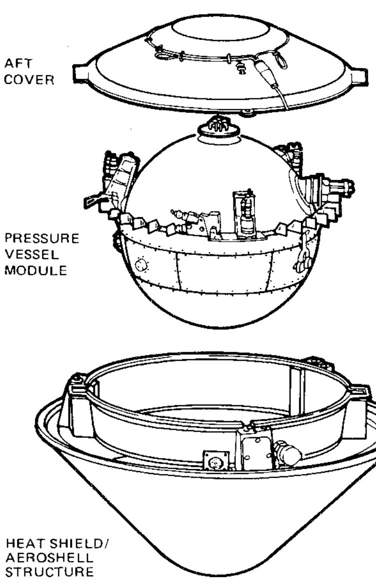


**Fig. 2 Large-probe exploded view.**

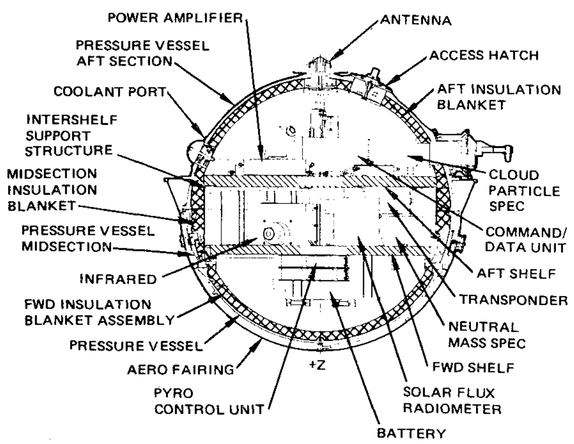


**Fig. 3 Large-probe pressure vessel internal arrangement.**

deceleration module also provides the pyrotechnic hardware for bus/probe separation, aft cover release, pressure vessel/aeroshell mechical separation, and jettison of the parachute. The pressure vessel contains the pyrotechnic devices for the electrical separation of the pressure vessel and aeroshell.

The pressure vessel module consists of a pressure vessel and the internal electronics and scientific instruments. The pressure vessel is designed to maintain an internal atmosphere of nitrogen ($N_2$) at an absolute pressure of 55 to 207 kPa while withstanding an external absolute pressure of 9653 kPa. The pressure shell is 73 cm in diam and approximately 0.6 cm thick and is constructed in three titanium pieces. The aft hemisphere provides mechanical access via a 9.5-cm port and ground cooling for test through a 6-cm port. It also has a port for the antenna and windows for two instruments. A midbay section includes the inlets and windows for the remaining scientific instruments and four electrical feedthroughs for electrical access to the pressure vessel. The forward section is separately removable for access to the forward bay. In all, there are 15 penetrations to the pressure vessel, and a total of 7.6 m of seals are required to prevent the nitrogen atmosphere from leaking out during transit or the hot Venus atmosphere from leaking in during descent. Internal equipment is mounted on two approximately 65-cm-diam beryllium shelves which provide heat sinking during descent. Thermal protection for the internal electronics is provided by a 2.5-cm, 41-layer Kapton blanket that is restrained by a titanium sheet

**Table 3 Large- and small-probe subsystem characteristics**

| | Large Probe | Small Probe |
|---|---|---|
| Power | Battery: 19 cell, Ag-Zn (40 A-hr) | 20 cell, Ag-Zn (11 A-hr) |
| | Electronics: 28 V ±10% 15 on/off relays | Same 10 on/off relays |
| Command | Onboard sequencer | Same |
| | 24-day timer | Same |
| | 128 stored command descent sequence | Same |
| Telemetry | Convolutionally encoded PCM/PSK/PM | Same |
| | 8-bit word, 64-word frames | Same |
| | 72 data channels | Same |
| | 2 formats | Same |
| | 3072 bit memory (blackout) | Same |
| | 256 bps | 16 and 64 bps |
| Communication | Crossed dipole omni antenna | Same |
| | 40 watt power amplifier | 10 W power amplifier |
| | S-band transponder | |

insulation retainer. The thermal design maintains the temperatures of electronics and instruments below 50°C even with an exterior temperature of 493°C. The general interior arrangement of the probe is seen in Fig. 3. A 78-cm-diam titanium sheet fairing covers the forward portion of the pressure vessel and provides the aerodynamic shape required for a stabilized aerodynamic descent in the Venus atmosphere. The structural and mechanical interface with the deceleration module is provided by a 9.7-cm-high titanium adaptor ring that is 89 cm in diam.

A summary of large-probe subsystem characteristics is given in Table 3. The large probe carries a payload of seven scientific instruments (see Table 2) with a combined mass of 35 kg and consuming 106 W of electrical power. Of the seven instruments, three require inlets for sampling the atmosphere, and four require windows for viewing the atmosphere. All of the windows are made of sapphire except the window for the infrared instrument. The need for transmissibility in the 10-$\mu$ region and the ability to withstand an absolute pressure of 9653 kPa and 493°C has led to the choice of natural diamond as the only material that can meet the requirements. The diamond window is approximately 1.8 cm diam and weighs 13 carats.

#### Small-Probe Description

The three small probes provide the capability for simultaneous measurement of Venus atmospheric characteristics at widely separated locations. For this reason, the small probe is designed to accommodate a range of entry angles from −20 to −75 deg and communication angles up to 60 deg. The small probe is a self-contained system after separation from the bus, operating on internal power and a preprogrammed command sequence. During entry in the Venus atmosphere, at a speed of 11.6 km/sec, the deceleration force will reach a maximum of 565 *g*. The probe will begin scientific measurements at an altitude greater than 65 km, and the descent time to the Venus surface will be 59 min. The probe will be designed to withstand the surface of an absolute pressure of 9653 kPa and 493°C but is not required to survive impact.

The small-probe mass is 97 kg and consists of a pressure vessel module and a deceleration module (shown in exploded view in Fig. 4). However, there is no parachute, and the small-probe pressure vessel module does not separate from the deceleration module. The deceleration module consists of a 76-cm-diam, 45-deg blunt cone aeroshell with a 19-cm nose radius. A carbon phenolic heatshield is bonded to the titanium aeroshell structure. A pyrotechnically released flyaway clamp restrains the probe while attached to the bus and is part of the deceleration module. The spin rate is reduced by a factor of 4

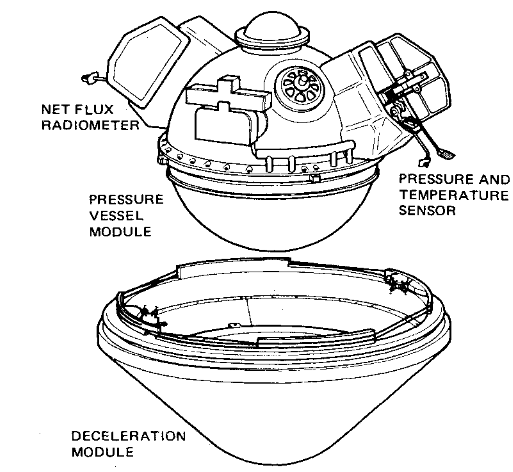


**Fig. 4 Small-probe external configuration.**

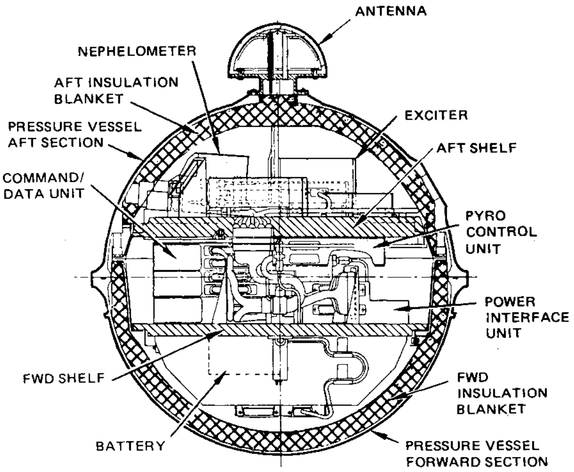


**Fig. 5 Small-probe pressure vessel internal arrangement.**

prior to entry by two pyrotechnically released despin weights (yo-yo's).

The pressure vessel module consists of a pressure vessel internal structure, the internal electronics, and scientific instruments. The pressure vessel is designed to maintain an internal atmosphere of xenon at an absolute pressure of 28 to 207 kPa. The two-piece titanium shell is 46 cm in diam and approximately 0.36 cm thick. It provides electrical access by three feedthroughs and mechanical access via a 9.5-cm inspection port. Three housings on the aft section provide entry protection for the deployment mechanisms, scientific instrument sensors, and optical ports. The deployment mechanisms (shown deployed) deploy two instruments after probe entry. Thermal protection for the contents of the shell is provided by a 61-layer Kapton blanket immediately adjacent to the pressure vessel wall. Heat capacity and a mounting surface for the internal electronics is provided by two 39-cm-diam shelves machined from hot-pressed beryllium block. The internal arrangement of the small probes is shown in Fig. 5. There are a total of eight penetrations to the small-probe pressure vessel and 2.7 m of seals. A summary of small-probe subsystem characteristics is given in Table 3.

#### Multiprobe Mission Description†

The multiprobe spacecraft launch will take place during the period from August 7-24, 1978, the launch window for the 1978 Venus type I launch opportunity. The launch vehicle will

†Final and more detailed mission planning may change some of the mission parameters described in this and the orbiter mission description.

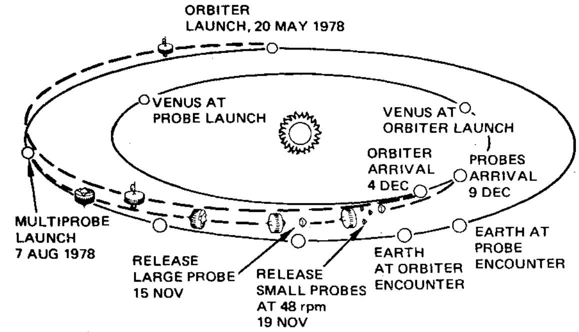


**Fig. 6 Mission interplanetary trajectories.**

place the multiprobe on the desired type I interplanetary trajectory as shown in Fig. 6 after a 12- to 18-min coast period in a 167-km Earth parking orbit. During the launch phase, spacecraft engineering telemetry will be transmitted from the forward omni antenna. Immediately prior to separation, the Centaur will orient the spacecraft to a normal-to-the-ecliptic attitude, with the positive spin axis in the direction of the South ecliptic pole. The separation switches will initiate a command sequence stored in the command processor memory which results in spacecraft spinup to approximately 15 rpm. It is expected that ground station acquisition, at Canberra, will occur within 4 hr after launch. Within the first few days, the jets will be calibrated in preparation for the first trajectory correction maneuver at $L+5$ days. This maneuver requires a velocity correction of up to 12.1 m/sec to correct launch vehicle injection errors. The maneuver will be performed in either a normal-to-the-ecliptic attitude or, after a precession around the sunline, to an attitude that allows use of axial jets. The selection will depend upon which mode minimizes propellant usage. Subsequent maneuvers, if required, will be performed at $L+20$ days and $E-34$ days to correct execution errors resulting from the preceding maneuvers. During transit to Venus, telemetry will be transmitted from the forward omni antenna. The command and control of the multiprobe normally will be exercised by utilizing the DSN 26-m network. During maneuver periods and probe checkouts starting at $L+60$ days, the 64-m antennas will be used.

At approximately $E-28$ days, the spacecraft spin axis will be precessed to an attitude in the ecliptic plane so that the medium-gain horn can be used for communications. The large probe is separated from the multiprobe at $E-24$ days. The release attitude is selected so that the probe will enter the atmosphere with a near-zero angle of attack. Immediately after release, the spin axis orientation will be precessed to the small-probe targeting attitude to allow use of the medium-gain horn. At $E-23$ days, the multiprobe will be spun up to 48.5 rpm, and a pulsed radial jet maneuver will be performed to effect a velocity correction of 5.1 m/sec to achieve the desired small-probe targeting. The three probes will be released at $E-20$ days. The 48.5-rpm spin rate will provide tangential velocity at separation sufficient to achieve the desired target points. Since the sun will be only 17 deg removed from the positive spin axis, the bus can only remain in the probe release attitude a total of 4 hr. Immediately after small-probe release, the spin axis will be precessed to an attitude that allows use of the medium-gain horn and provides a sun angle of 40 deg. At $E-18$ days, a velocity correction maneuver of 19.1 m/sec will move the trajectory aim point to that desired for bus entry and slow the arrival by 90 min so that the bus will arrive after impact of all probes on Venus. At $E-8$ days, the bus will be oriented to the final entry attitude, and at $E-2$ days, the bus will be despun to 10 rpm. The scientific instruments will then be checked out, and on Dec. 9, 1978, the bus will arrive at Venus and provide the desired sampling before its destruction during atmospheric entry at approximately 110 to 120 km alt.

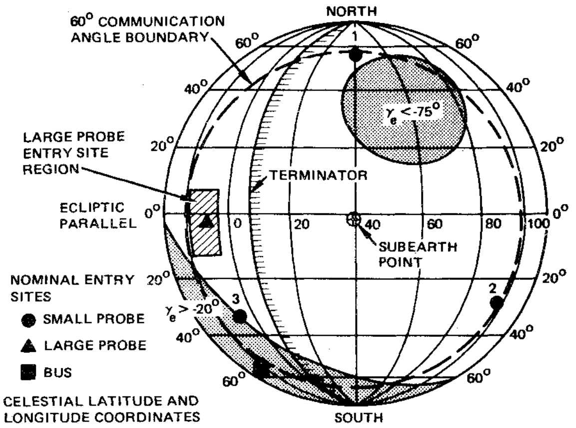


Fig. 7 Probe and bus entry sites as viewed from Earth.

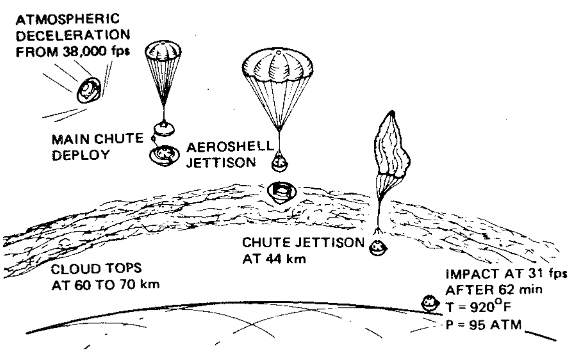


Fig. 8 Large-probe descent.

The nominal entry sites for the bus and four probes are shown in Fig. 7. The entry of all five spacecraft will take place over a period of 2 hr and all will be operating simultaneously. To assure no loss of data, the spacecraft entry will be timed to be in view of two DSN stations.

### Large-Probe Mission Description

At the time of large-probe release, the bus is aligned with the expected probe entry velocity vector so that the nominal entry angle of attack is near zero. Since the bus spins at 15 rpm at release, the large probe will be spin-stabilized at 15 rpm during the 24-day coast. During this period, the only unit operating is the coast timer, which is set prior to separation so as to initiate probe operation prior to Venus entry.

The Venus entry and descent phase is shown schematically in Fig. 8. At 2½ hr prior to the expected entry time, the coast timer turns on the receiver in preparation for entry operation. At 22 min prior to entry, the probe spacecraft subsystems are turned on, and DSN acquisition of the probe carrier signal is established. Then 5 min later, the instruments are turned on, and calibration data are transmitted at 256 bps. At 5 min prior to entry, the spacecraft is configured for the entry phase. The data rate is reduced to 128 bps and is stored in the 3072-bit memory. During entry, the probe will experience high deceleration levels (nominally 323 *g*), high heating rates, and a communication blackout period for approximately 10 sec. After completion of the entry phase, as measured by an acceleration switch at 5.5 *g* decreasing deceleration, the spacecraft is reconfigured to the normal descent mode, the data rate is increased to 256 bps, and communication is reestablished with Earth. Shortly afterwards, the parachute is deployed, extracting the pressure vessel module from the deceleration module. The pressure vessel descends on the parachute from 67 to 46 km alt. At 18 min after entry, the parachute is jettisoned, and the pressure vessel continues to descend, impacting the Venus surface approximately 56 min after initial entry.

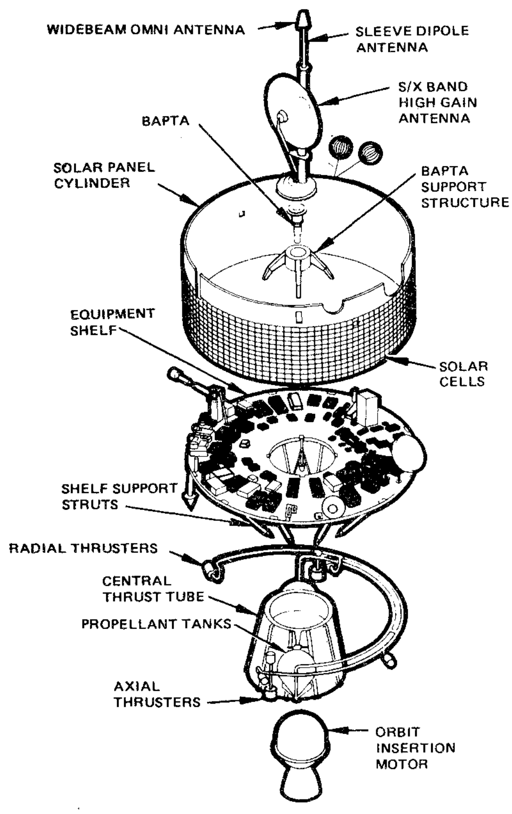


Fig. 9 Orbiter exploded view.

### Small-Probe Mission Description

The small-probe coast timer is set by the bus, prior to separation, to activate the stable oscillator and battery heater 2 hr prior to entry. At 22 min prior to entry, the probe spacecraft subsystems are turned on, and the unmodulated carrier is transmitted for DSN acquisition. Then 5 min later, scientific instruments are turned on, and calibration data are transmitted at 64 bps. At 5 min prior to entry, the yo-yo's are deployed, reducing the spin rate by a factor of 4 to 12 rpm. At the same time, the blackout configuration is established, and scientific data are stored in the memory during the brief (5 to 13 sec) blackout periods that the small probes experience during their entry deceleration (up to 565 *g*). The nominal descent configuration is re-established by the accelerometer sensing the deceleration decreasing below 5.5 *g*. At this time, the doors that protect the pressure inlet, temperature sensor, and net flux radiometer from the entry heating open, and two booms deploy the sensor into the freestream. Scientific data are transmitted back to Earth at 64 bps for the next 16 min. At that time, at approximately 30 km alt, the data rate is reduced to 16 bps (to allow for reduced rf transmission throughout the atmosphere). Impact will occur at approximately 59 min after entry.

## Orbiter Mission

### Orbiter Spacecraft Description

The primary mission of the orbiter is to place a payload of 12 scientific instruments in orbit around Venus. As can be seen in Fig. 9, the orbiter shares much in common with the bus spacecraft. The substitution of a high-gain antenna for the probe support structure and the addition of an orbit insertion motor and a deployable 4.6-m magnetometer boom are the principal differences. The despun high-gain antenna provides communication with the Earth at ranges as great as $250 \times 10^6$ km. The orbit insertion motor is used to place the orbiter spacecraft in a 24-hr orbit around Venus. The entire orbiter, including its Centaur attach fitting, has a mass of 599 kg at launch and 372 kg in orbit around Venus.

Table 4 Orbiter scientific payload

| Instrument/Principal Investigator | Measurement Objective |
|---|---|
| Retarding Potential Analyzer W. Knudsen, LMSC | Physics and ion chemistry of the ionosphere |
| Ion Mass Spectrometer H. Taylor, GSFC | Composition of the ionosphere and charged particle concentrations (< 4,000 km) |
| Electron Temperature Probe L. Brace, GSFC | Electron temperature and density profiles of the ionosphere |
| Ultraviolet Spectrometer A. Stewart, U. of Colo. | Energy balance of the thermosphere; ionization rates; O, CO, $CO_2$ composition |
| Neutral Mass Spectrometer H. Niemann, GSFC | Composition of the upper atmosphere and neutral particle concentrations (< 500 km) |
| Cloud Photopolarimeter J. Hansen, GISS | Polarimetry of the planet on a global scale (far from periapsis); pictorial mapping |
| Infrared Radiometer F. Taylor, JPL | Thermal structure of the lower atmosphere and the vertical distribution of particulate matter |
| Magnetometer C. Russell, UCLA | Measure interplanetary and means of the Venus magnetic field from the lower ionosphere to the solar wind |
| Plasma Analyzer J. Wolfe, ARC | Interaction of solar wind with the ionosphere |
| Radar Mapper Radar Mapper Team | Topography and electrical properties of the surface (< 7000 km) |
| Electric Field Detector F. Scarf, TRW | Mapping of the solar wind bow shock; mode of interaction of the solar wind and the ionosphere |
| Gamma Ray Burst Detector W. Evans, LASL | Measure gamma ray emanations from outer space; correlate with sensors in other locations for pinpointing of sources |
| S-X Band RF Occultation RF Science Team | Derive temperature and pressure in the lower atmosphere (down to ~35 km); map electron profiles and neutral atmosphere density distribution and vertical cloud structure |

Thermal control of the orbiter is provided by 15 louvers mounted to the underside of the equipment shelf, various heaters on elements of the propulsion subsystem and the underside of the shelf, aluminized Kapton thermal blankets, and appropriate thermal finishes and paints. Much of the electronics on the orbiter is common to the bus, with some unique equipment to accommodate special orbiter requirements. A summary of orbiter subsystem characteristics is given in Table 1.

The orbiter payload consists of 12 scientific instruments that can weigh up to a maximum of 48 kg. Table 4 summarizes the principal investigator and the scientific objective of each instrument. The instruments utilize a maximum of 40 W of electrical power during transit to Venus and 90 W in orbit. The magnetometer is placed at the tip of a 4.6-m boom to isolate it from spacecraft magnetic fields. A 750-m X-band transmitter and the S-band communication link are used for a dual-frequency occultation experiment. A high-gain antenna positioner mechanism provides capability of offset the S- and X-band beams ±15 deg in elevation as it enters and exits Venus occulation.

### Orbiter Mission Description

The orbiter will be launched with an Atlas SVL-3D/Centaur D-1AR launch vehicle from CCAFS, Fla. Launch will take place during the 1978 type II Venus launch window in the period from May 20-June 2, 1978. The launch vehicle will place the orbiter on the desired interplanetary trajectory after a 12- to 18-min coast period in a 167-km Earth parking orbit. During the launch phase, spacecraft engineering telemetry will be transmitted via the spacecraft forward omni antenna. The Centaur, immediately prior to separation, will orient the orbiter in an approximately normal-to-the-ecliptic attitude with the positve spin axis in the direction of the North ecliptic pole. Spacecraft separation switches initiate a command sequence stored in the command processor which results in spacecraft spinup to 6 rpm. It is expected that ground station acquisition at Canberra will occur within 4 hr after launch. After a preliminary attitude and spin rate determination, the magnetometer boom will be deployed by ground command. After spinup to 15 rpm and an engineering checkout of the spacecraft, the high-gain antenna will be despun, and jets can be calibrated in preparation for the first trajectory correction maneuvers at $L+5$ days. This maneuver requires a velocity correction of up to 7.5 m/sec to correct launch vehicle injection errors. This maneuver will be performed in normal-to-the-ecliptic attitude using successive firings of axial and radial jets to achieve the desired direction. Subsequent maneuvers, if required, will be performed at $L+20$ days and $E-20$ days to correct execution errors resulting from the preceding maneuvers. Several scientific instuments, notably those associated with interplanetary fields and particles, will operate during the transit to Venus. Others will be periodically checked out and calibrated. Telemetry will be transmitted via either the high-gain antenna or the forward omni antenna. Command and control of the orbiter will normally be exercised utilizing the DSN 26-m net except when maneuvers are performed. During these periods, the 64-m stations will be used.

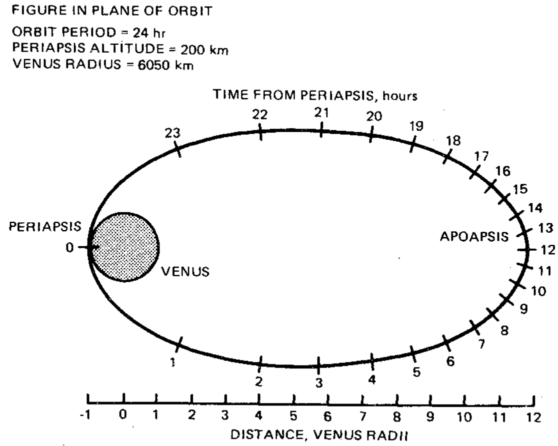


Fig. 10 Spacecraft hourly location in nominal orbit.

Type II transit to Venus, shown in Fig. 6, initially travels outside the Earth's orbit, reaching a maximum distance of $161 \times 10^6$ km from the sun before coasting inward toward rendezvous with Venus. Approximately 2 days before nominal arrival at Venus at 1800 hr GMT on Dec. 4, 1978, the orbiter spin axis will be precessed to the orbit insertion attitude and the spacecraft spun up to 30 rpm. In this attitude, with the positive spin axis directed approximately toward the ecliptic North pole, the sun angle ranges from 85 to 95 deg and the communications (Earth) angle from 64.5 to 78.5 deg, depending upon the launch day. Communications will be maintained using the forward omni antenna and the 64-m DSN net. The orbit insertion motor will be fired at closest approach to Venus (350 to 450 km alt) to place the orbiter in a 24-hr, Venus-centered orbit. Since motor firing occurs behind the planet relative to Earth, the necessary commands will be stored in the command memory. The selected orbit, shown in Fig. 10, is inclined 75 deg to the Venus equator, with motion being in a retrograde direction. Periapsis will be located at 15 to 32 deg lat, depending on the launch date. Shortly after orbit insertion, the spacecraft will undergo engineering checkout, the spin axis will be reoriented approximately 180 deg so that the positive spin axis is directed toward the South ecliptic pole (for in situ sampling at periapsis), and the spin rate will be reduced to 5 rpm for scientific data collection. The orbital period will be corrected at the first periapsis, $E+24$ hr, and the periapsis altitude will be lowered to 200 km at the second apoapsis, $E+36$ hr.

The nominal orbiter mission will last for 243 Earth days (one Venus day). For this duration, the period will be adjusted to remain at approximately 24 hr, so that periapsis will remain in view of the same Earth tracking station. Solar perturbations, if uncorrected, will cause periapsis altitude to increase. Axial jet firings made near apoapsis will, however, lower periapsis altitude to 150 km at least eight times, approximately even spaced during the 243-day mission. The periapsis maximum altitutde will be limited to 260 km. Operation of the scientific instruments will take place principally near periapsis, where atmospheric sampling and radar mapping is best, although several instruments will operate throughout the orbit. The cloud photopolarimeter will generate spin-scan uv pictures in the apoapsis portion of the orbit.

The despun high-gain antenna will provide both uplink and downlink capability throughout the mission. During the first 40 orbits, an occultation experiment will be conducted using both S- and X-band frequencies radiated toward the Earth through the fringe of the Venus atmosphere as the orbiter passes behind the planet. The 64-m DSN stations will be utilized for this experiment. Occultations will occur during two periods: near periapsis for the first 75 days of the orbital mission, and near apoapsis between $E+156$ and $E+165$ days. Periods of combined solar eclipse and occultation occur from $E+25$ through $E+75$ days. Since the eclipse duration is at most 23 min, full spacecraft operations can be maintained using energy supplied by the battery. The longer eclipses, up to 3.8 hr, that occur later in the mission from $E+183$ to $E+189$ days require that the orbiter be powered down to a survival mode. Extensive use will be made of the data storage capability and the command memory during orbital operations to minimize the time required on the ground to monitor spacecraft operations. The $1\times10^6$-bit data storage unit will be used to store scientific instrument data recorded around periapsis and for other periods during the orbit for playback at later times. The 26-m DSN net will be utilized for data gathering and spacecraft command. A 24-hr command sequence will be stored in the command memory and need not be updated for several days, as the orbital geometry does not change rapidly.

## Low-Cost Aspect

One of the major objectives of the Pioneer Venus program has been to accomplish the mission at minimum program costs. This requirement has permeated the approach to the program and has been successful in keeping the costs of a relatively ambitious program at a minimum. Some of the more important approaches to savings costs are described below.

### Launch Vehicle Selection

In 1973, NASA elected to utilize the Atlas-Centaur launch vehicle rather than the Thor-Delta launch vehicle in order to provide increased launch weight capability. The increased weight allowed the use of more conventional and less expensive technologies and the more extensive use of existing designs.

### Protoflight

The amount of hardware which is to be built and tested has been minimized to save costs. Most significant has been the deletion of prototype spacecraft hardware. Hence, only one multiprobe and one orbiter spacecraft will be built, tested, and flown. The conventional prototype spacecraft, which in the past has been standard for a complex new development program, has been omitted in the Pioneer Venus program. This has resulted in a substantial reduction in cost and an increase in risk. The risk has been minimized by an extensive structural and thermal test program emphasizing the unique new environments imposed by the Pioneer Venus mission.

### Commonality

A further economy was achieved in the Pioneer Venus program by utilizing the same hardware configurations in different spacecraft. For example, the same standard communication power amplifier is used in the bus, orbiter, and probes. Identical command and data-handling equipment is used in all probes, even though the requirements are different. Similarly, much of the electronics in the bus and orbiter are identical. From a quantitative standpoint, approximately 78% of the bus units are common to the orbiter units. Approximately 32% of the small-probe units are identical to the large-probe units, and 14% of the large-probe units are identical to the bus units. This has substantially reduced the amount of hardware which had to be developed and has also reduced the amount of spares required.

### Existing Design

The use of existing designs was made an important part of the design approach. The bus/orbiter configuration relies heavily on previous Hughes communication and scientific spacecraft designs. Approximately 43% of the units are identical to previously flown spacecraft hardware. Approximately 30% are modified from previous hardware. The remaining 27% are new, most of them being in the probes, where there is no substantial experience to rely on. It is significant to note that, in those areas where existing design was used, costs have been relatively low and predictable.

On the other hand, in the new area, the probes, cost has been relatively high and hard to predict. The design of lightweight structure, harness, windows, seals, electrical feedthroughs, parachutes, etc., to withstand the high levels of entry acceleration, the corrosive acids, and the high temperature and pressure of the Venus atmosphere has proven challenging. Verifying the design has demanded the development of unique new test facilities to simulate the hostile Venus environment. The same characteristics that make Venus an interesting planet to explore make it a technically challenging planet to explore.

## Conclusions

The Pioneer Venus program is an ambitious undertaking. Six new spacecraft—the orbiter, bus, large probe, and three small probes—are being designed and developed simultaneously and are being integrated with a total of 30 science instruments. The probes spacecraft are especially difficult, since they will have to withstand the hostile and partially unknown environment of Venus. This has resulted in a number of unique and difficult design and test problems. An additional constraint is the low-cost aspect of the program. Every effort has been made to minimize cost without any significant reduction in program confidence. The completion of a successful Pioneer Venus mission in 1978 will represent a major advance in our understanding of Venus and a significant accomplishment in the development of spacecraft technology. It will have required the dedicated participation of a large number of people in NASA, the scientific community, and the industrial community.

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