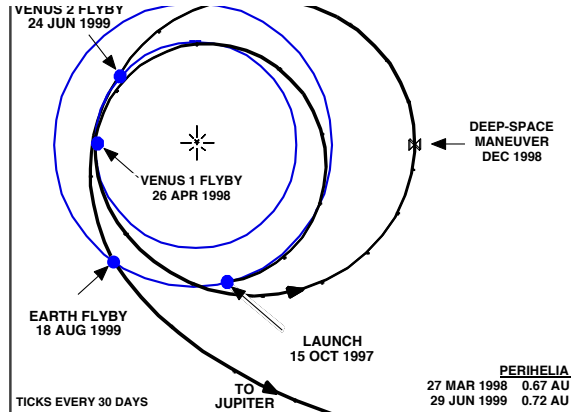


Cruise Phase

Science Observations During Cassini Inner Cruise Phase

After launch, Cassini followed a Venus-Venus-Earth-Jupiter gravity assist (VVEJGA) trajectory en route to Saturn.



Cassini Trajectory, Inner Solar System (figure 5.1 from Cassini Mission Plan, Rev L)

To constrain flight operations during interplanetary cruise, only minimal spacecraft activity was planned until Saturn arrival. During most of the Inner Cruise Phase (the time period from 14 November 1997 through 7 November 1999), the spacecraft's proximity to the Sun constrained the spacecraft to remain Sun-pointed such that the High-Gain Antenna (HGA) shaded the spacecraft, and therefore telecommunications used the low data rate Low Gain Antennas (LGAs) and the downlink capability was limited. The engineering activities onboard the spacecraft were geared towards maintenance and calibration of engineering subsystems and provided support for the trajectory correction maneuvers (TCMs) and deep space maneuvers (DSMs). Limited resources were allocated to planning science observations before launch, and cruise science was planned to be limited. During this mission phase, there were numerous constraints limiting spacecraft operations and constraining spacecraft orientation.

Instrument Checkout Phase

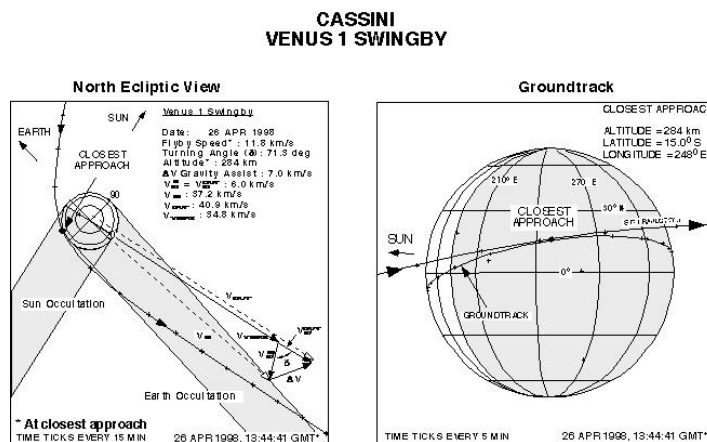
Approximately 14 months after Cassini's launch, the thermal constraints allowed the spacecraft to point its high gain antenna toward Earth for a period of approximately 25 days as the spacecraft approached opposition. This period provided the first extended post-launch opportunity for the science community to check out their instruments. The Instrument Checkout Period (referred to as ICO-1) began on December 28, 1998 and extended through January 21, 1999.

The Cosmic Dust Analyzer (CDA) was powered on March 25, 1999. The instrument did not operate continuously during early cruise and because of the spacecraft orientation, was often not sensitive to impacts by interstellar or interplanetary dust grains. Until November, 1999 the

spacecraft was oriented such that the high-gain antenna was oriented to protect the spacecraft from dust impacts.

Venus-1

The Venus-1 flyby occurred on April 26, 1998, just 6 months after launch. There were few scientific observations during that first encounter. Scientific data were obtained in the search for lightning conducted by the Radio and Plasma Wave Science (RPWS) instrument [Gurnett, 2001]. The Radio Science (RSS) instrument was able to serendipitously capture the electron density profile of Venus's ionosphere while supporting telecommunication to the Earth. The spacecraft approached Venus from a sunward direction, and closest approach occurred just after entering the Sun's shadow for a period of about 15 minutes. At closest approach, the altitude was 284 km, with a velocity relative to Venus of 11.8 km/s. The geometry of the flyby is shown in figure 2.



Geometry of the Cassini Venus-1 flyby in April, 1998 (figure 5.3 of the Cassini Mission Plan Rev L).

Venus-2

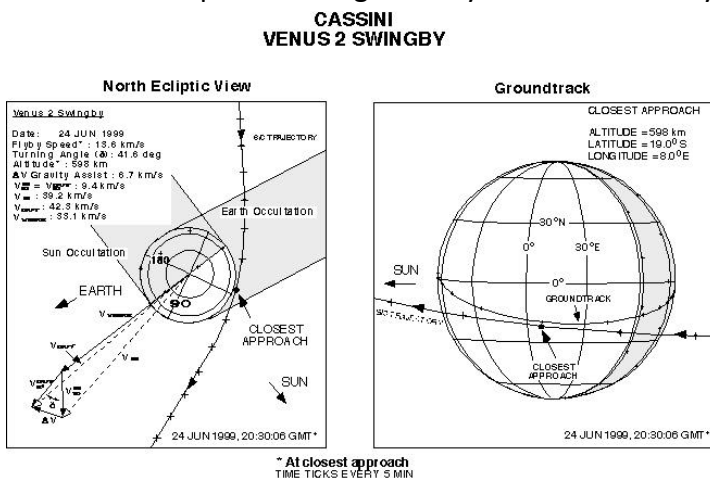
The second Venus flyby (Venus-2) occurred on June 24, 1999. The Venus-2 and the Earth-Moon swing-by constituted the first period of significant scientific activity for the mission. An overview of the observations obtained during the second Venus flyby (Venus-2) and Earth swingby is given in [Burton et al., 2001] and many of the science observations are summarized in a collection of articles published in this same volume [Journal of Geophysical Research, Vol. 106, No. A12]. The geometry of the flyby is shown in figure 5-4 of the Cassini Mission Plan, Rev L. Cassini's trajectory in a Venus-center reference frame for the Venus-1 and 2 flybys are shown in figure of Gurnett [2001].

Designing science observations that did not violate pointing constraints was a major challenge and limited the science data obtained. Pointing constraints included 1) aligning the Huygens probe in the direction of spacecraft velocity to provide a shield from micrometeoroids 2) orienting the high-gain antenna toward the Sun to shade the spacecraft 3) keeping sunlight, either direct or reflected from bright bodies, out of the field of view of the stellar reference

units (SRUs) which provide stellar navigation data used for attitude control 4) limiting the thermal exposure for the radiators of the Visual and Infrared Mapping Spectrometer (VIMS) and Composite Infrared Spectrometer (CIRS) instruments. All these constraints were met when choosing a spacecraft attitude for the Venus 2 and Earth flybys but restricted the science observations.

Venus-2

The second Venus flyby occurred on June 24, 1999. Closest approach occurred at 2030 UT at an altitude of 603 km with a Venus-relative velocity of 13.6 km/s. Approach to Venus was from the dusk side of the planet. The geometry of the Venus-2 flyby is shown in figure 3.



Geometry of Cassini Venus-2 flyby in June, 1999 (figure 5-4 of Cassini Mission Plan, Rev. L).

The Cassini Plasma Spectrometer (CAPS), magnetometer (MAG), Magnetospheric Imaging Instrument (MIMI) and Radio and Plasma Wave (RPWS) instruments were powered on several hours before closest approach. CAPS did not operate at Venus due to a software bug that was subsequently analyzed and fixed well in advance of the Earth swing-by. The magnetometer remained stowed in its launch canister for thermal reasons, however it was activated primarily to help identify boundaries such as the bowshock crossings in support of other instruments. Inbound and outbound bowshock crossings were identified by significant jumps in the magnetic field. Fields and particles science observations reported include MIMI CHEMS measurements in the ionosheath and stagnation region and MIMI INCA observations of energetic neutral atoms, and plasma wave measurements by RPWS. RPWS repeated their search for lightning as they did on the Venus-1 flyby.

Several hours before the flyby the spacecraft performed a roll of 34.4 degrees about the z-axis to allow the planet to pass through the fields of view of the optical remote sensing instruments at closest approach. The requirement to keep the high-gain antenna Sun-pointed allowed for a roll only about the z-axis. The Imaging Science Subsystem (ISS), the Ultraviolet Imaging Spectrograph (UVIS) and the Visual and Infrared Mapping Spectrometer (VIMS) were sequenced to observe for a short period (~12 minutes). Most of the ground track occurred over

the nightside of the planet. VIMS reported on thermal emission from the surface [Baines, 2000] UVIS made measurements of airglow [Stewart, 2000] and ISS took advantage of the flyby to obtain a flat-field calibration of the Wide-Angle Camera (WAC) and Narrow-Angle Camera (NAC).

Earth Swing-by

There was a relatively brief 54-day interval between the Venus and Earth encounters. Closest approach to Earth was at an altitude of 1186 km on 03:28 UT on August 18, 1999. The geometry of the flybys is also shown in figure 4.

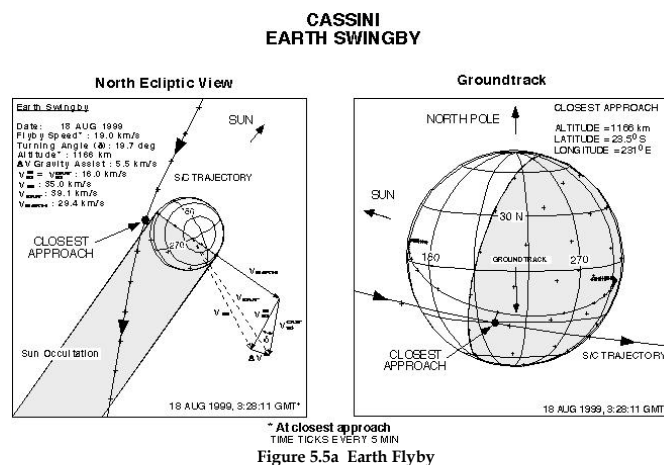


Figure 5.5a Earth Flyby

Geometry of Cassini Earth flyby (figure 5.5 of Cassini Mission Plan, Rev L).

Cassini approached Earth roughly along the noon meridian and flew by the Earth at a high rate of speed, ~ 9 Earth radii per hour, providing a snapshot of Earth's magnetosphere on a short timescale. Figure 1 of Lagg [2000] shows the Earth flyby trajectory in Geocentric Solar Equatorial (GSE) coordinates.

The fields and particles instruments were turned on up to several days before Earth closest approach and obtained many hours of data in the solar wind. One major objective of the Earth swing by was to obtain a critical calibration of the magnetometer sensors in the Earth's magnetosphere [Smith et al, 2001]. Forty-four hours before Earth swing-by, on August 16, the 11-meter magnetometer boom was unlatched and allowed to deploy. Since launch, the boom had been stowed in a cylindrical canister and deployment in the inner solar system. Thermal restrictions limited the boom deployment to sometime after the last outbound passage of 0.97 AU (which occurred 5 days prior to Earth).

Once the magnetometer boom was deployed, the Earth's well-known magnetic field was used to calibrate the magnetometer and to validate the absolute accuracy of the scalar mode of operation of the helium magnetometer which was used in high field ranges. The Science Calibration and Alignment (SCAS) subsystem, which produces a magnetic field vector in a direction that is accurately known, was operated several times to determine the alignment of

the magnetometer boom with respect to spacecraft axes. SCAS was used for about five hours during near-Earth MAG operation: two hours while the MAG boom was being deployed, about one and one-half hour before entering the Earth's magnetosphere, and one and one-half hours after exiting the Earth's magnetosphere. During the Earth swing-by, the fluxgate magnetometer was operated [Southwood, 2001] while the helium magnetometer was operated in its scalar mode [Smith, 2001]. The helium magnetometer switched from vector to scalar mode at around 4 Earth radii inbound and outbound, a total duration of only 1 hour.

As Cassini flew by Earth, the fields and particles instruments were able to identify all the typical magnetospheric boundaries and regions including the bowshock, magnetosheath, magnetopause, radiation belts, plasmasphere, plasma sheet, lobes and crossings of the tail magnetopause. The inbound bowshock was detected at 0151 UT on August 18 at ~15 Rs along the noon meridian and the first magnetopause observed shortly thereafter (0226 UT at 9.8 Earth radii). Key boundary crossings and other events are given in table of 1 of Lagg [2001].

The spacecraft orientation was not optimal for CAPS to obtain the best view of the plasma distributions to which they are sensitive, however all the CAPS sensors did return useful data [Rymer et al., 1999]. MIMI LEMMS obtained data during the Earth swing-by. In addition to demonstrating the instrument's performance, and were able to test models of energetic particle distributions in Earth's magnetosphere [Lagg et al., 2001]. MIMI INCA returned energetic neutral atom images of the Earth's ring current. RPWS captured a snapshot of the terrestrial magnetosphere with radio and plasma wave data obtained during the swing-by [Hospodarsky, 1999 and Kurth, 1999]. During the Earth swingby, a large international campaign of data gathering was carried out to support magnetospheric observations [Khan et al., 2001]. The observations compiled during the swingby included data from multiple spacecraft in the solar wind or magnetosphere (eg., ACE, IMP 8 Geotail, Wind), measurements of magnetic disturbances from a large network of ground-based observatories, ionospheric flows measured by ground-based radar observations and high resolution auroral images obtained by the Polar spacecraft. The suite of observations provided sufficient data to clearly define the state of the interplanetary medium and the state of the magnetosphere for the Earth swingby interval. These data and data obtained by the Cassini measurements confirmed that the flyby took place when the magnetosphere was generally in a disturbed state.

The orientation of the spacecraft allowed for the moon to pass through the fields of view of the optical remote sensing instruments. ISS, UVIS and VIMS observed the Moon, which was at quarter phase for as long as it was in their fields of view. For the WAC this was the longest, ~ 29 minutes. The Moon was in the field of view of the VIMS solar port for approximately an hour and a half, allowing the acquisition of important calibration data. After closest approach the flyby geometry was such that the high-gain antenna pointed at the Earth. This allowed several minutes for the RADAR instrument to transmit and receive at track of data over the southeastern Pacific Ocean, extending across South America [Lorenz, 2001]. The goal of this measurement was to perform an end-to-end test using the Earth as a target. This was the last opportunity for such a test before the first RADAR observation of Titan after reaching the

Saturnian system. The Radio Science Instrument (RSS) used the Earth swingby to look for evidence of an anomalous gravitational acceleration [Anderson and Williams, 2001].

The fields and particles instruments were able to collect data through opposition (nearly 7000 Earth radii past closest approach) in mid-September, 1999. MAG continued to make measurements after the Earth swingby until day 262, with intermittent outages necessary for engineering operations, (trajectory correction maneuver and Huygens Probe engineering activities). CDA remained on after the Earth swingby, collecting science data throughout the remainder of the sequence.

The scientific results of this mission phase are described in a collection of eleven scientific articles that appeared together in a special issue, First Results from Cassini: Venus and Earth Swing-Bys in the *Journal of Geophysical Research: Space Physics*, in December, 2001.

A second checkout period (ICO-2) occurred in July and August, 2000 when the high gain antenna was routinely in use. On 1 October 2000, Jupiter approach science began using a repeating 5-day template. The Jupiter flyby occurred on 30 December 2000 at a distance of 9.7 million km.

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