2.4 Cassini/Huygens

Introduction

Huygens is the element contributed by ESA to Cassini/Huygens, the joint NASA/ESA planetary mission to the Saturnian system. Titan, the largest moon of Saturn, is a central target of the mission. The Saturn Orbiter is provided by NASA, while the Italian Space Agency (ASI) has contributed its high-gain antenna and other radio subsystem equipment under a bilateral NASA/ASI agreement. The Jet Propulsion Laboratory (JPL, Pasadena, California) is managing the mission for NASA. The overall mission is named after the French/Italian astronomer Jean-Dominique Cassini, who discovered several Saturnian satellites and ring features, including the Cassini division, during 1671-1685. ESA's probe is named after Dutch astronomer Christiaan Huygens, who discovered Titan in 1655.

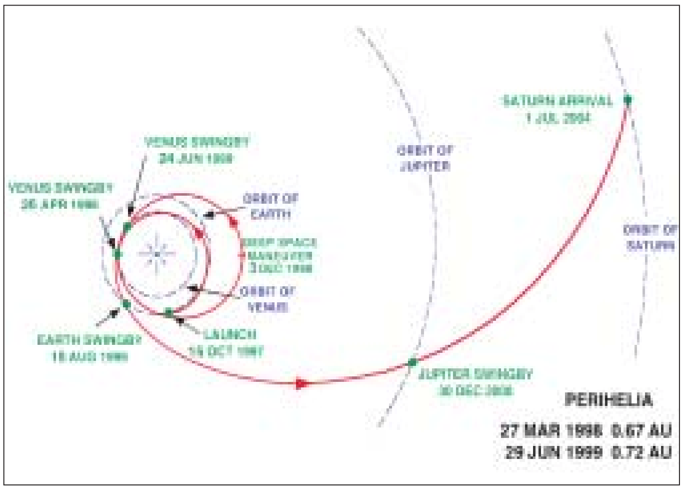
The Cassini/Huygens spacecraft was launched on 15 October 1997 by a Titan IVB-Centaur rocket from Cape Canaveral Air Force Station in Florida. The 5.6 t spacecraft was too heavy to be injected into a direct trajectory to Saturn, so the interplanetary voyage of about 6.7 years includes gravity-assist manoeuvres at Venus, Earth and Jupiter (Fig. 2.4.1). Upon arrival at Saturn, the spacecraft will be inserted into orbit around Saturn. At the end of the third revolution around Saturn, the Orbiter will deliver the Huygens Probe to Titan. After completion of the Probe mission, the Orbiter will carry out its exploration of the Saturnian system during 75 orbits around Saturn over 4 years. It will make repeated close flybys of Titan, both for data gathering about the moon and for gravity-assist orbit changes that will permit it to make a tour of Saturn's satellites, reconnoitre the magnetosphere and obtain views of Saturn's higher latitudes. During its 4-year nominal mission, Cassini will make detailed observations of Saturn's atmosphere, magnetosphere, rings, icy satellites and Titan.

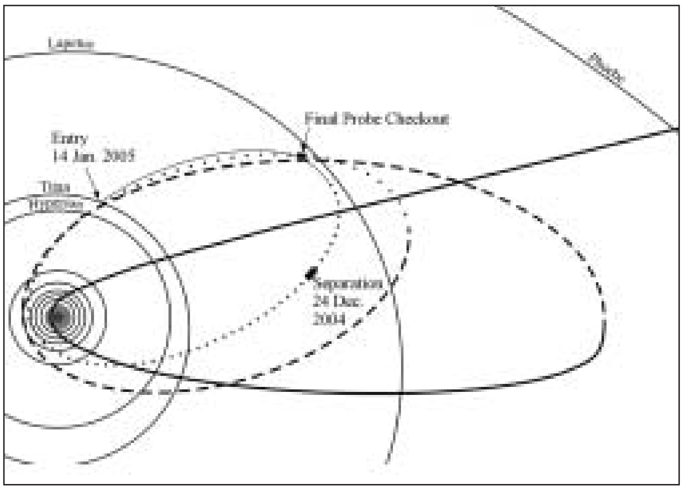
The Huygens Probe was selected by ESA's Science Programme Committee in November 1988 as the first medium-size mission of the Horizon 2000 long-term scientific programme. NASA received approval for the start of Cassini in 1990.

Scientific objectives

The Cassini/Huygens mission is designed to explore the Saturnian system and all its elements: the planet and its atmosphere, rings and magnetosphere, and a large number of its moons, particularly Titan and the icy satellites. Titan is the second largest moon in the Solar System after Jupiter's Ganymede. Its atmosphere resembles that of the

Figure 2.4.1. Left: the interplanetary trajectory of the Cassini/Huygens spacecraft. Right: the trajectory upon arrival at Saturn; the Probe is released towards the end of the initial orbit around Saturn.





For further information, see http://sci.esa.int/huygens

Table 2.4.1. The principal characteristics of the Huygens payload.

Instrument/PI	*Science objectives*	*Sensors/measurements*	*Mass (kg)*	*Power (typical/ peak, W)*	*Participating countries*
Huygens Atmospheric Structure Instrument (HASI) M. Fulchignoni, University Paris 7/ Obs. Paris-Meudon (France)	Atmospheric temperature and pressure profile, winds and turbulence Atmospheric conductivity. Search for lightning. Surface permittivity and radar reflectivity.	T: 50-300K, P: 0-2000 mbar γ: 1 μg-20 mg AC E-field: 0-10 kHz , 80 dB at 2 μV/m Hz DC E-field: 50 dB at 40 mV/m Conductivity 10^{-15} Ω/m to ∞ Relative permittivity: 1 to ∞ Acoustic: 0-5 kHz, 90 dB at 5 mPa	6.3	15/85	I, A, D, E, F, N, SF, USA, UK, ESA/RSSD, IS
Gas Chromatograph Mass Spectrometer (GCMS) H.B. Niemann, NASA/GSFC, Greenbelt (USA)	Atmospheric composition profile. Aerosol pyrolysis products analysis.	Mass range: 2-146 dalton Dynamic range: $>10^8$ Sensitivity: 10^{-10} mixing ratio Mass resolution: 10^{-6} at 60 dalton GC: 3 parallel columns, H_2 carrier gas Quadropole mass filter 5 electron impact sources Enrichment cells (×100-×1000)	17.3	28/79	USA, A, F
Aerosol Collector and Pyrolyser (ACP) G.M. Israel, SA/CNRS Verriéres-le-Buisson (France)	Aerosol sampling in two layers – pyrolysis and injection to GCMS	2 samples: 150-40 km; 23-17 km 3-step pyrolysis: 20°C, 250°C, 600°C	6.3	3/85	F, A, USA
Descent Imager/Spectral Radiometer (DISR) M.G. Tomasko, University of Arizona, Tucson (USA)	Atmospheric composition and cloud structure. Aerosol properties. Atmospheric energy budget. Surface imaging.	Upward and downward (480-960 nm) and IR (0.87-1.64 μm) spectrometers, res. 2.4/6.3 nm. Downward and side looking imagers. (0.660-1 μm), res. 0.06-0.20° Solar Aureole measurements: 550±5 nm, 939±6 nm. Surface spectral reflectance with surface lamp.	8.1	13/70	USA, D, F
Doppler Wind Experiment (DWE) M.K. Bird, University of Bonn (Germany)	Probe Doppler tracking from the Orbiter for zonal wind profile measurement.	(Allan Variance) : 10^{-11} (1 s); 5×10^{-12} (10 s); 10^{-12} (100 s) Wind measurements 2-200 m/s Probe spin, signal attenuation	1.9	10/18	D, I, USA
Surface Science Package (SSP) J.C. Zarnecki, University of Kent, Canterbury (UK)	Titan surface state and composition at landing site. Atmospheric measurements.	γ: 0-100 g; tilt ±60°; T: 65-110K; T_{th}: 0-400 mW m^{-1} K^{-1} Speed of sound: 150-2000 m s^{-1}, Liquid density: 400-700 kg m^{-3} Refractive index: 1.25-1.45 Acoustic sounding, liquid relative permittivity	3.9	10/11	UK, F, USA, ESA/RSSD, PL

Table 2.4.2. The Huygens interdisciplinary scientists.

Scientist/Affiliation	*Field of Investigation*
ESA Selection	
D. Gautier, Obs. de Paris, Meudon, F	Titan aeronomy
J.I. Lunine, Univ. of Arizona, Tucson, USA	Titan atmosphere/surface interactions
F. Raulin, LPCE, Univ. Paris 12, Creteil, F	Titan chemistry and exobiology
NASA Selection	
M. Blanc, Observatoire Midi-Pyrénées, Toulouse, F	Plasma circulation and magnetosphere/ ionosphere coupling
J. Cuzzi, NASA Ames Research Center, Moffett Field, USA	Rings and dust within Saturnian system
T. Gombosi, Univ. of Michigan, Ann Arbor, USA	Plasma environment in Saturn's magnetosphere
T. Owen, Inst. for Astronomy, Honolulu, USA	Atmospheres of Titan and Saturn
J. Pollack (deceased), NASA Ames Research Center, Moffett Field, USA	Origin and evolution of Saturnian system
L. Soderblom, US Geological Survey, Flagstaff, USA	Satellites of Saturn
D. Strobel, Johns Hopkins University, Baltimore, USA	Titan's and Saturn's atmospheric aeronomy

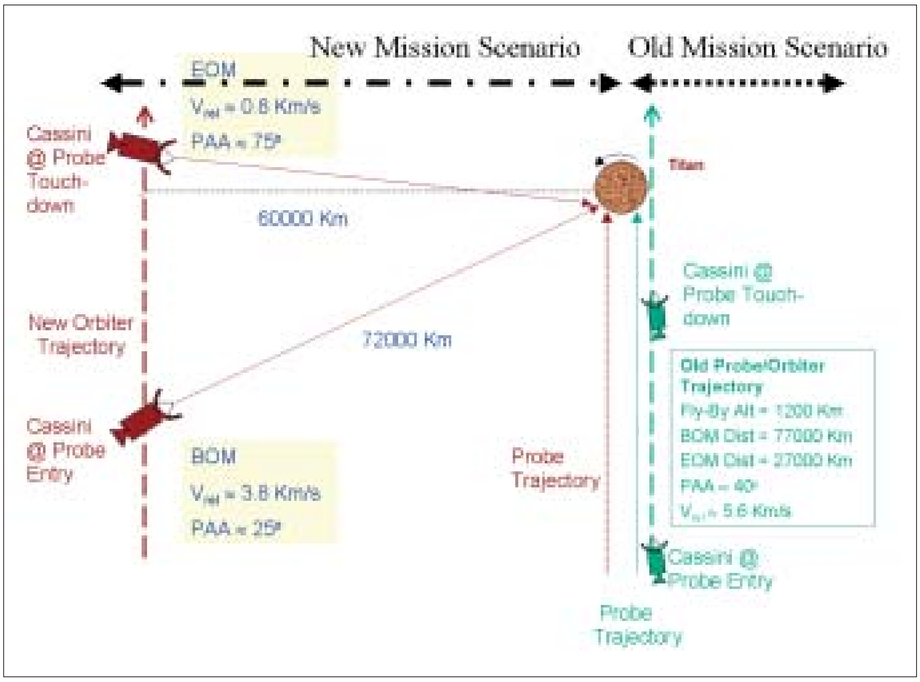
Earth more closely than that of any other Solar System body. Nitrogen is the major constituent, at a surface pressure of 1.5 bar, compared with 1 bar on Earth. Other major constituents are methane (a few percent) and hydrogen (0.2%). It is speculated that argon could also be present (the most recent models suggest an upper limit of 1%), although it has not yet been detected. Another resemblance to Earth is that Titan's surface could be partially covered by lakes or even oceans of methane and ethane mixtures. The photolysis of methane in the atmosphere, owing mainly to the solar UV radiation but also to cosmic rays and precipitating energetic magnetospheric particles, gives rise to a complex organic chemistry. Chemical reactions taking place in the continuously evolving atmosphere provide possible analogues to some of the prebiotic organic chemistry that was at work on the primitive Earth, before the appearance of life some 3.8 Gyr ago.

Huygens will carry out a detailed *in situ* study of Titan's atmosphere and to characterise the surface of the satellite near the Probe's landing site. The objectives are to make detailed *in situ* measurements of the atmosphere's structure, composition and dynamics. Images and spectroscopic measurements of the surface will also be made during the atmospheric descent. Since it is hoped that the Probe will survive after the impact for at least a few minutes, the payload includes the capability for making *in situ* measurements for a direct characterisation of the surface at the landing site.

The payload

On 10 October 1989, NASA and ESA simultaneously released coordinated Announcements of Opportunity (AOs) calling respectively for investigations to be performed with the Saturn Orbiter and the Huygens Probe. The NASA AO called for four types of proposals:

Figure 2.4.2. The revised approach strategy for Huygens at Titan.



— Principal Investigator (PI) Instruments;
— Orbiter facility team leader (TL);
— Orbiter facility team member (TM);
— Interdisciplinary Scientist (IDS) investigation.

The ESA AO called for two types of proposals:
— PI Instrument;
— Interdisciplinary Scientist investigation.

The ESA Huygens selection, which comprises six PI Instruments (Table 2.4.1) and three IDS investigations (Table 2.4.2), was announced in September 1990. The NASA Saturn Orbiter selection, which comprised seven PI Instruments, four Team Leaders, 52 Team Members and seven IDS investigations, was announced in November 1990. During the selection process, NASA included an additional facility instrument on the Orbiter, the Ion and Neutral Mass Spectrometer (INMS), for which a call for Team Leader and Team Member investigation proposals was released in August 1991. The INMS investigation selection was announced in February 1992. The NASA-selected IDS is shown in Table 2.4.2 and the Orbiter Payload in Table 2.4.3.

Cassini/Huygens mission overview

The Cassini/Huygens spacecraft will arrive at Saturn in late June 2004. The Saturn Orbit Insertion (SOI) manoeuvre will be executed while the spacecraft is crossing the ring plane on 1 July 2004. This manoeuvre will place the spacecraft in a 90-day orbit, which includes the first targeted Titan flyby. The second (48-day) orbit, which also includes a targeted Titan flyby, will shape the trajectory so that the Huygens mission can be carried out on the third (32-day) orbit using an Orbiter flyby altitude of 60 000 km. The Huygens mission trajectory was changed in 2001 to accommodate a new geometry requirement during the Probe relay phase that reduces the Doppler shift

Table 2.4.3. Saturn Orbiter payload.

Instrument *PI*	*Measurement*	*Technique*	*Mass (kg)*	*Power (W)*	*Countries*
Optical Remote Sensing					
Composite Infrared Spectrometer (CIRS) V. Kunde, NASA/GSFC, USA	High-resolution spectra, 7-1000 µm	Spectroscopy using 3 interferometric spectrometers	43	43.3	USA, F, D, I, UK
Imaging Science Subsystem (ISS) C. Porco, U. Arizona, USA	Photometric images through filters, 0.2-1.1 µm	Imaging with CCD detectors; 1 wide-angle camera (61.2 mrad FOV); 1 narrow-angle camera (6.1 mrad FOV)	56.5	59.3	USA, F, D, UK
Ultraviolet Imaging Spectrometer (UVIS) L. Esposito, U. Colorado, Boulder, USA	Spectral images, 55-190 nm; occultation photometry, 2 ms; H and D spectroscopy, 0.0002 µm resolution	Imaging spectroscopy, 2 spectrometers; hydrogen-deuterium absorption cell	15.5	14.6	USA, F, D
Visible and Infrared Mapper Spectrometer (VIMS) R. Brown, U. Arizona, Tucson, USA	Spectral images, 0.35-1.05 µm (0.073 µm resolution); 0.85-5.1 µm (0.166 µm resolution); occultation photometry	Imaging spectroscopy; 2 spectrometers	37.1	24.6	USA, F, D, I
Radio Remote Sensing					
Cassini Radar (RADAR) C. Elachi, JPL, USA	Ku-band radar images (13.8 GHz); radiometry, <0.5K resolution	Synthetic aperture radar; radiometry with a microwave receiver	43.3	108.4	USA, F, I, UK
Radio-Science Instrument (RSS) A. Kliore, JPL, USA	Ka/S/X-bands; frequency, phase, timing and amplitude	X/Ka-band uplink; Ka/X/S-band downlink	14.4	82.3	USA, I
Particle Remote Sensing & In-Situ Measurement					
Magnetospheric Imaging Instrument (MIMI) S.T. Krimigis, Johns Hopkins Univ, Baltimore, USA	1. Image energetic neutrals and ions at <10 keV to 8 MeV per nucleon; composition. 2. 10-265 keV/e ions; charge state; composition; directional flux; 3. mass range: 20 keV to 130 MeV ions; 15 keV to >11 MeV electrons; directional flux	1. Particle detection and imaging; ion-neutral camera (time-of-flight, total energy detector); 2. charge energy mass spectrometer; 3. solid-state detectors with magnetic focusing telescope and aperture-controlled ~45° FOV	29	23.4	USA, F, D
In-Situ Measurement					
Cassini Plasma Spectrometer (CAPS) D.T. Young, SWRI, San Antonio, USA	Particle energy/charge: 1. 0.7-30 000 eV/e; 2. 1-50 000 eV/e 3. 1-50 000 eV/e	Particle detection and spectroscopy: 1. electron spectrometer; 2. ion-mass spectrometer; 3. ion-beam spectrometer	23.8	19.2	USA, SF, F, H, N, UK
Cosmic Dust Analyser (CDA) E. Gruen, MPI Heidelberg, D	Directional flux and mass of dust particles in the range 10^{-16}-10^{-6} g; chemical composition	Impact-induced currents	16.8	19.3	D, CZ, F, ESA/RSSD, N, UK, USA
Dual Technique Magnetometer (MAG) D. Southwood, IC, UK	B: DC to 4 Hz up to 256 nT; scalar field DC to 20 Hz up to 44 000 nT	Magnetic field measurement; flux gate magnetometer; vector-scalar magnetometer	8.8	12.4	UK, D, USA
Ion and Neutral Mass Spectrometer (INMS) J.H. Waite, SWRI, San Antonio, USA	Fluxes of +ions and neutrals in mass range 2-66 amu	Mass spectrometery; closed source and open source	10.3	26.6	USA, D
Radio and Plasma Wave Science (RPWS) D. Gurnett, U. Iowa, USA	E: 10 Hz-2 MHz; B: 1 Hz-20 kHz; plasma density and temperature	Radio frequency receivers; 3 electric monopole antennas; 3 magnetic search coils; Langmuir Probe	37.7	17.5	USA, A, F, S, UK, N

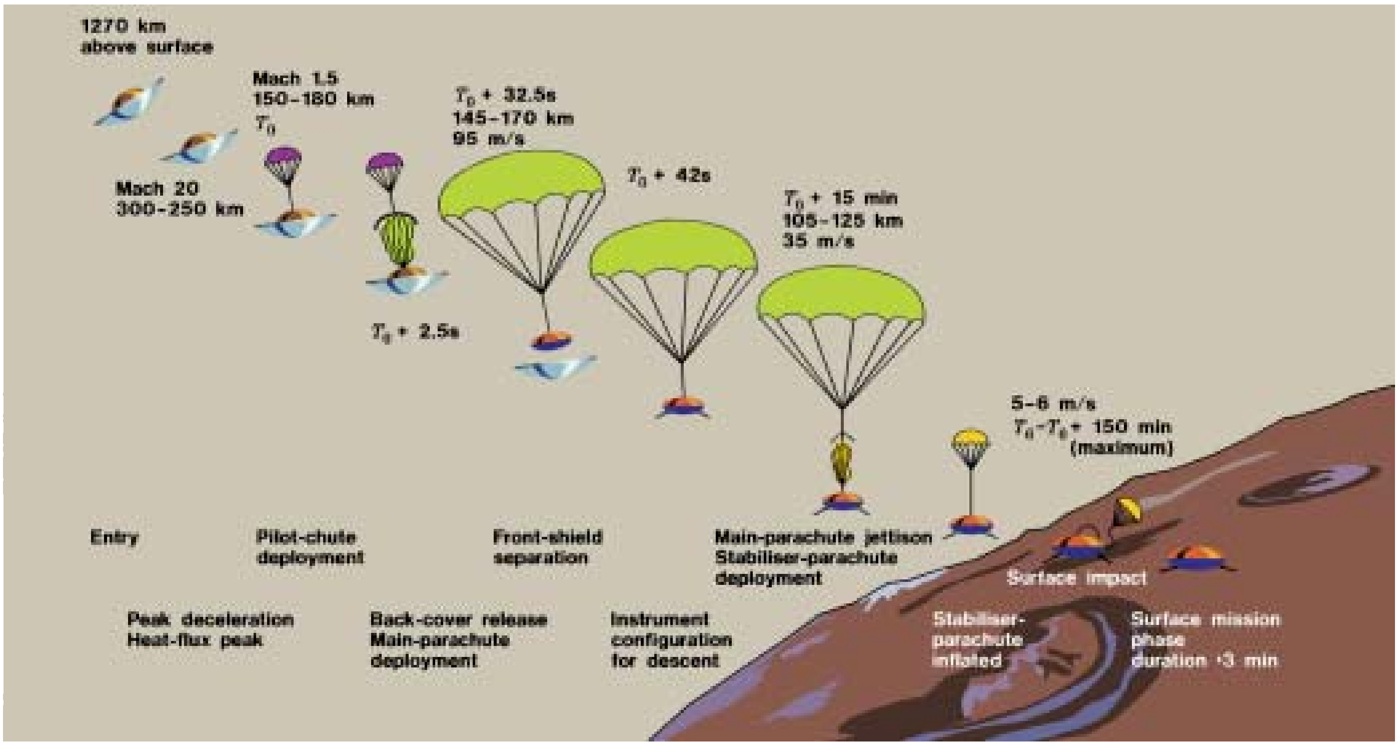


Figure 2.4.3. The entry and descent sequence for the Huygens Probe.

of the radio signal received by the Orbiter (Fig. 2.4.2). This change was necessary to cope with a design flaw of the Huygens radio receiver discovered during inflight testing in 2000. The onboard software of the Probe and several instruments was also modified in December 2003 to optimise the mission recovery. The Probe will be released on 25 December 2004, 22 days before Titan encounter. Five days after release, the Orbiter will perform a deflection manoeuvre in order to avoid impacting Titan. This manoeuvre will also set up the Probe-Orbiter radio communication geometry for the Probe descent phase. Huygens' entry into Titan's atmosphere is planned for 14 January 2005. The Orbiter will act as a relay during the Huygens mission, receiving the data on its High Gain Antenna (HGA). This configuration does not allow the Probe mission to be conducted with a real-time link between the Orbiter and Earth. The Probe data will be stored aboard the Orbiter in the two solid-state recorders for later transmission to Earth after completion of the Probe mission. The main events of the Probe entry and descent are illustrated in Fig. 2.4.3.

After completion of the Probe mission, the Orbiter will begin its 4-year satellite tour of the Saturnian system. This consists of 75 Saturn-centred orbits, connected by Titan gravity-assist flybys or propulsive manoeuvres. The size of these orbits, their orientation to the Sun/Saturn line and their inclination to Saturn's equator are dictated by the various scientific requirements, which include: Probe and landing site ground-track coverage, icy-satellite flybys, Saturn, Titan or ring occultation, magnetosphere coverage, orbit inclinations and ring-plane crossings. Titan is also a principal target for the Orbiter; it will be observed during each of the 44 targeted Titan flybys.

The Orbiter science instruments are mounted on two body-fixed platforms: the remote-sensing pallet and the particle & field pallet; the magnetometer is mounted at the tip of an 11 m-long boom; the magnetic and electric antennas of the RPWS

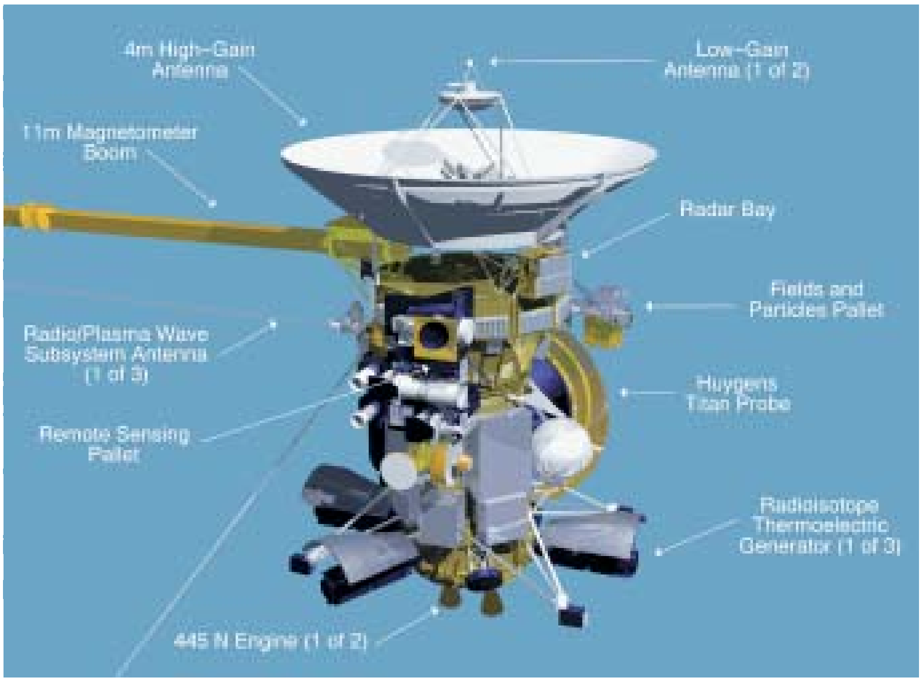


Table 2.4.4. Mass breakdown of the Cassini/Huygens spacecraft.

Orbiter (dry, inc. payload)	2068 kg
Probe (inc. 44 kg payload)	318 kg
Probe Support Equipment	30 kg
Launch adaptor	135 kg
Bipropellant	3000 kg
Monopropellant	132 kg
Launch mass	5683 kg

Figure 2.4.4. The Cassini/Huygens spacecraft and its principal features.

experiment are mounted on the body; both the radar and the radio-science instrument use the HGA. The main elements of the Cassini/Huygens spacecraft are illustrated in Fig. 2.4.4. The mass budget of the spacecraft is shown in Table 2.4.4.

Huygens flight operations

After separation from the Orbiter, the Probe will operate autonomously, the radio relay link to the Orbiter being one-way for telemetry only. Up to that point, telecommands can be sent via an umbilical link from the Orbiter, but this facility will be used only during the cruise and Saturn orbit phases for monitoring the health of the subsystems and calibrating the instruments during the 6-monthly checkouts. Huygens does not perform scientific measurements before arrival at Titan and for most of the cruise the Probe is switched off. It is activated only for a 3-7 h period for the biannual checkouts. During the 22-day coast phase after separation from the Orbiter, only a timer will operate, to activate the Probe about 265 min before the predicted entry into Titan's atmosphere. Loading the value of this timer's duration and depassivating the batteries that power the Probe after separation will be the last activities initiated by command from the ground.

The Probe flight operations, and the collection of telemetered data, are controlled from a dedicated control room, the Huygens Probe Operations Centre (HPOC) at ESOC (Darmstadt, Germany). Here, command sequences are generated and transferred by dedicated communication lines to the Cassini Mission Operations Center at JPL. There, the Probe sequences are merged with commands to be sent to other subsystems and instruments of the Orbiter for uplink via NASA's Deep Space Network (DSN). Probe telecommands are stored onboard the Orbiter and forwarded to the Probe Support Equipment (PSE) at specified times (time tags) for immediate execution. Because of the great distance of Saturn from Earth (requiring up to 2.5 h for round-trip radio communication) real-time operations are not possible during the Probe descent.

Data collected by the Probe and passed to the PSE via the umbilical (during the cruise) or the relay link (during the descent) will be formatted by the PSE and forwarded to the Orbiter's Command and Data Subsystem (CDS). The Orbiter stores all data on solid-state recorders for transmission to Earth at times when it is visible from one of the DSN ground stations. From the ground station, the data are forwarded to JPL, where Probe data are separated from other Orbiter data before being stored on the Cassini Project Database (PDB). HPOC operators access the PDB to retrieve Probe data via a Science Operations and Planning Computer (SOPC), supplied to ESOC by JPL under the terms of the interagency agreement.

Probe subsystem housekeeping data are used by ESOC to monitor the performance of the Probe, while data from the science instruments are extracted for forwarding to the investigators. During the cruise phase, these data are shipped to the scientists' home institutes by public data line or on CD-ROMs. After analysis of these data, the investigators meet the operations team to review the results of the previous checkout and to define the activities for the following checkout period. During the Saturn orbit and Probe mission phases, the investigators will be located at HPOC to expedite their access to the data and facilitate interaction with their colleagues and the Probe operators. Accommodation will be provided for the ground support equipment they need to reduce and interpret their data.

All in-flight Probe activities are prepared very carefully as any mistake could endanger its mission performance. Each checkout sequence is tested on the Probe Simulator and then on the Engineering Model (EM), both installed in HPOC. The EM has been retrofitted with flight spare computers and the instrument interfaces upgraded to flight standard. It was used as a testbed to validate all the modifications to the Probe's onboard software.

Status

Venus, Earth and Jupiter encounters

Unique science observations were made during the second Venus encounter (24 June 1999), the Earth encounter (18 August 1999) and the 6-month Jupiter flyby campaign (October 2000 to March 2001). The Saturn approach science phase began in early January 2004, providing continuous observations of the system. Result highlights are available at *http://saturn.jpl.nasa.gov*

Saturn Orbiter

After the very successful launch and injection of Cassini/Huygens on its interplanetary trajectory, Cassini/Huygens performed four nominal planet flybys: Venus-1 (26 April 1998), Venus-2 (24 June 1999), Earth (18 August 1999) and Jupiter (30 December 2000). The flight performances of the spacecraft are excellent. The Orbiter software for the two critical sequences, the SOI manoeuvre (1 July 2004)and the Probe Relay Link (early- to mid-January 2005), were full tested in flight.

Huygens Probe

Thirteen inflight checkouts have been conducted. The payload and subsystem performance have been as expected. An end-to-end test of the Probe relay link was carried out in February 2000, using a DSN antenna to transmit a simulated Probe radio signal. This test uncovered a malfunction in the Huygens radio receivers. After intensive investigations supported by further inflight and ground tests, it was found that, owing to a design flaw, the bandwidth of the bit synchroniser of the Huygens radio receivers was too narrow. It could not cope with the expected Doppler shift from the relative displacement between the two spacecraft during the Probe mission. It would have led to significant Huygens data loss, but a change in the Orbiter trajectory and other changes in Probe operations will allow recovery of the full Probe mission.