THE HUYGENS MISSION TO TITAN: OVERVIEW AND STATUS

Jean-Pierre Lebreton(1), Dennis L. Matson(2)

(1) *Research and Scientific Support Department, ESA/ESTEC, Postbus 299, 2200 AG Noordwijk, The Netherlands, Email: jplebret@rssd.esa.int*

(2) *Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109-8099, Email: dmatson@jpl.nasa.gov*

ABSTRACT

The Huygens Probe is part of the NASA/ESA/ASI Cassini/Huygens mission to Saturn and Titan. The spacecraft was launched on 15 October 1997 from Cape Canaveral Air Force Station, Florida, USA. It will reach its target, Saturn, and will go into orbit around it, on 1 July 2004. Huygens will be released from the Saturn Orbiter on 25 December 2004 and will plunge in Titan's atmosphere 3 weeks later, on 14 January 2005. It will descend by parachute to the surface in about 2 to 2 ½ hours. During the whole descent, it will transmit data to the over-flying Orbiter. If it survives the landing, it will continue transmitting until it freezes. The orbiter will fly over the Probe´s horizon 4 ½ hours after the start of the descent. In this paper we give a brief overview of the probe mission. Aspects related to the reconstruction of the trajectory of the probe are emphasized. The status of the mission is briefly discussed.

1. CASSINI/HUYGENS MISSION OVERVIEW

The Cassini/Huygens mission [1] is designed to explore the Saturnian system and all its elements: the planet and its atmosphere, its rings, its magnetosphere and a large number of its moons, including Titan and the larger icy satellites. The mission will emphasize the exploration of Titan, Saturn's largest moon and the Solar System's second largest (after Jupiter's Ganymede), and the only satellite with a thick atmosphere.

The Cassini/Huygens spacecraft (Fig. 1) was launched on 15 October 1997 by a Titan 4B/Centaur rocket from Cape Canaveral Air Station in Florida. With a launch mass of 5650 kg, it was too massive for a direct injection towards Saturn. Cassini/Huygens used a Venus-Venus-Earth-Jupiter gravity assist interplanetary trajectory and a fixed arrival date at Saturn of 1 July 2004 (Fig. 2).

Upon arrival at Saturn, the spacecraft will make a close swingby of the planet at 1.3 Rs (Saturn radii) and execute the Saturn Orbit Insertion (SOI) propulsive maneuver. This puts Cassini/Huygens into a highly elliptical, 116-day orbit around the planet. Two days after SOI, on 3 July 2004, observations of Titan are planned during the distant flyby called T0, (339000 km at closest approach). This first orbit sets the geometry for the first targeted encounter with Titan (Ta), on 26 October 2004, the second encounter with Titan (Tb) on 12 December 2004, and the third encounter (Tc) on 14 January 2005.

Fig. 1: The Cassini/Huygens spacecraft during assembly. Huygens is attached on the side of the propulsion module.

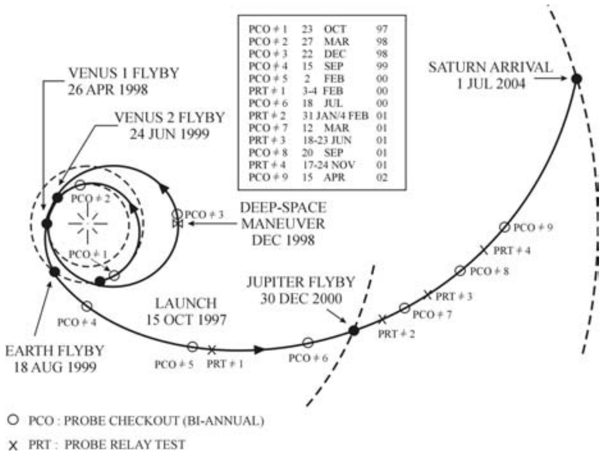

Fig. 2: Cassini/Huygens Interplanetary trajectory. The position of the spacecraft for the main Huygens in-flight activities is indicated

The Tc encounter is for executing the Probe mission; it also sets up the subsequent satellite encounters during the four-year orbital tour. Fig. 3 shows the spacecraft flight path for the approach to Saturn, the SOI maneuver, and the initial 3 orbits around Saturn. During the nominal four-year mission, the spacecraft will make 77 orbits around Saturn. 45 of the orbits include targeted flybys of Titan at altitude as low as 950 km above the surface.

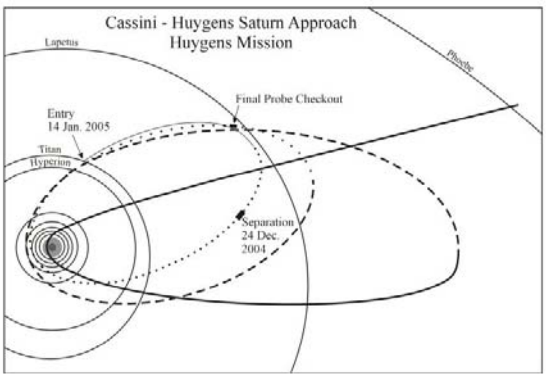

Fig. 3: Cassini/Huygens flight path showing the Saturn approach trajectory and the 3 first orbits around Saturn.

The Huygens Probe is carried to Titan attached to the Saturn Orbiter through its spin-and-eject mechanism. The probe will be released from the orbiter approximately 21 days before the third Titan flyby, Tc. Three days after probe release, the Orbiter will perform a deflection maneuver to place itself on the proper trajectory that will over-fly the probe landing site. When the Probe approaches Titan, the Orbiter points its High-Gain Antenna (HGA) at the predicted Probe landing point on the surface to receive telemetry from the Probe during the whole descent and while on the surface until the Orbiter goes below the Probe´s horizon.

2. HUYGENS MISSION OVERVIEW

2.1 Huygens Scientific Objectives

The scientific objectives of the Huygens mission [1,2] at Titan are to:

- Determine abundance of atmospheric constituents (including noble gases); establish isotope ratios for abundant elements; constrain scenarios of formation and evolution of Titan and its atmosphere;

- Observe vertical and horizontal distributions of trace gases; search for more complex organic molecules; investigate energy sources for atmospheric chemistry; model the photo-chemistry of the stratosphere; study formation and composition of aerosols;

- Measure winds and global temperatures; investigate cloud physics, general circulation and seasonal effects in Titan's atmosphere; search for lightning discharges;

- Determine the physical state, topography and the composition of the surface; infer the internal structure of the satellite;

- Investigate the upper atmosphere, its ionization, and its role as a source of neutral and ionized material for the magnetosphere of Saturn.

Huygens will carry-out a detailed *in-situ* study of Titan’s atmosphere and to characterise the surface of the satellite along the descent ground track and in the vicinity of the landing site. The objectives are to perform detailed *in-situ* measurements of atmospheric structure, composition and dynamics. Images and other remote sensing measurements of the surface will also be made during the descent through the atmosphere. A descent time of between 2 and 2½ hour is planned. The Probe is expected to impact the surface at 5-6 m/s. Since Huygens may survive touch-down, the payload includes an instrument for characterizing the surface. The entry and descent scenario is illustrated in Fig. 4.

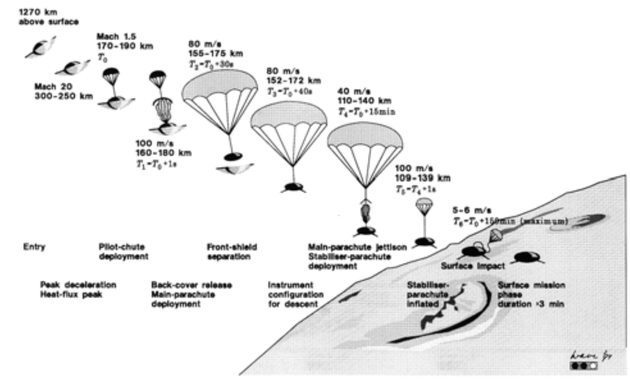

Fig. 4: Huygens Entry and Descent Scenario.

The Probe will start transmitting data to the Orbiter after the main parachute deployment. The trajectory during this phase is shown in Fig. 5. The data link between the Probe and the Orbiter can last 4 ½ hours. It is terminated as the Orbiter flies over the horizon.

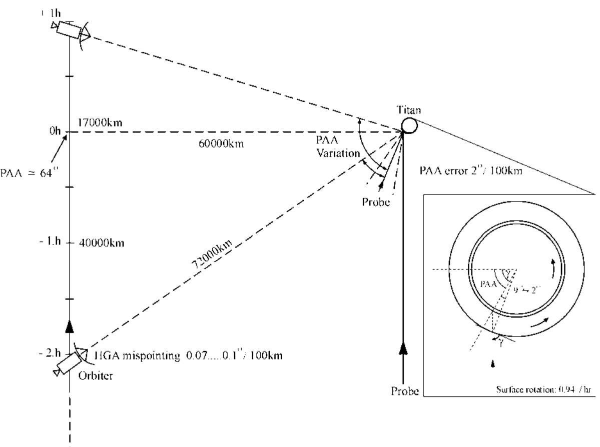

Fig. 5: Orbiter Trajectory during the Probe mission

If everything proceeds nominally, the Probe batteries may function for half-an-hour, or possibly more. This would be a bonus for the mission. The current mission scenario allows more than 2 hours of communication with the Probe on the surface. A surface lifetime of only a few minutes would permit a rapid characterization of the state and composition of the landing site. A longer time would allow a detailed analysis of the physical and chemical composition of surface material.

2.2 Titan characteristics

Titan is the second largest moon of the solar system and it is the only one with a thick atmosphere. The main atmospheric constituent is N_2. The surface pressure is about 1.5 bar (i.e., 1.5 times the Earth's). The equatorial surface temperature is about 94K and the temperature of the tropopause, at an altitude around 45 km, is about 70K. Other major constituents are CH_4 (a few %) and H_2 (0.2%). It is speculated that argon could also be present in quantities ≤ 6%. The physical properties of Titan are listed in Table 1.

Surface radius	2575±0.5 km
Mass	1.346×10^{23} kg (2.2% of M_{earth})
GM	8978.1 km^3/s^2
Surface gravity	1.345 m/s^2
Mean density	1.881 g/cm^3
Distance from Saturn	1.226×10^6 km (20.3 R_S)
Orbital period	15.945 d
Rotation period	15.945 d
Surface temperature	~94 K (equator)
Surface pressure	~1500 mbar

Table 1: Physical properties of Titan.

2.2 Titan engineering models

The design of the Huygens Probe mission required the establishment of several "engineering models" for Titan that provided a sound basis for various trade-offs and performance calculations during the Probe's development. These models were created thanks to the close working relationship between the Huygens scientists who provided the knowledge (and the speculations) and the Huygens engineers who provided the engineering wisdom and the necessary engineering conservatism that led to a robust Probe design. The engineering models are all documented in ESA SP-1177 [3]. Huygens was designed using the Lellouch-Hunten model as the reference atmospheric structure [see ref. 3]. The reference atmosphere is now the Yelle model [see ref. 3]. Gravity waves are also taken into account as described by the Strobel-Sicardy model [see ref. 3]. The evolution of the zonal-wind model considered for the design of the mission has been reviewed recently [Ref. 4].

2.3 Huygens Payload

The Huygens payload consists of six instruments provided by Principal Investigators. The list of the payload is provided in Table 2. A brief description of each instrument is given below; more detailed descriptions are in the individual instrument papers in [3, 5].

Instrument /Acronym	Scientist /Affiliation	Brief Objectives
Aerosol Collector Pyroloser (ACP)	G. Israel (PI), CNRS/Service d'Aeronomie (F)	*In situ* aerosol properties
Descent Imager and Spectral Radiometer (DISR)	M. Tomasko (PI), University of Arizona (USA)	Spectrophotometry; heat flux, imaging
Doppler Wind Experiment (DWE)	M. Bird (Universität Bonn (D)	Zonal wind
Gas Chromatograph and Mass Spectrometer (GCMS)	H. Niemann, NASA/GSFC, (USA)	Chemical composition of gas and aerosol phases; isotopic measurements
Huygens Atmospgheric Structure Instrument (HASI)	M. Fulchignoni, Univ. Paris-7, and Obs de Paris-Meudon, (F)	Atmosphere physical and electrical properties
Surface Science Package (SSP)	J. Zarnecki, Open University (UK)	Surface structure and composition

Table 2: Huygens payload

Gas Chromatograph and Mass Spectrometer (GCMS)

The Gas Chromatograph Mass Spectrometer (GCMS) is designed to measure the chemical composition of Titan's atmosphere from 170 km altitude (≈0.1 mbar) to the surface (≈1500 mbar) and determine the isotope ratios of the major gaseous constituents. GCMS will also analyze gas samples from the Aerosol Collector and Pyrolyzer (ACP) and will investigate the composition (including isotopic ratios) of several candidate surface materials.

GCMS is a quadrupole-mass-spectrometer analyser with a secondary–electron-multiplier detection system and a gas sampling system that provides continuous direct atmospheric composition measurements and batch sampling through three gas chromatograph (GC) columns. The mass spectrometer employs five ion sources that sequentially feed the mass analyser. Three ion sources serve as detectors for the GC columns and two are dedicated to direct atmosphere sampling and gas sampling for the ACP respectively. The instrument is also equipped with a chemical scrubber cell to prepare samples for noble gas analysis, and a sample enrichment cell for selective measurement of high boiling-point carbon-containing constituents. Its mass range is 2-141 amu and the nominal detection threshold is for a mixing ratio of 10^{-8}.

GCMS has also the capability, thanks to its heated inlet, to determine the chemical composition of a vaporised surface material sample in the event that landing allows the collection and transmission of data for several minutes from the surface.

Aerosol Collector and Pyrolyser (ACP)

ACP is designed to collect aerosols which the GCMS analyses for their chemical composition. It is equipped with a deployable sampling device that will be operated twice during the descent in order to collect an aerosol sample in two different altitude ranges: the first sample from the top of the atmosphere down to about 40 km, and the second sample in the cloud layer from about 23 km down to 17 km. After extension of the sampling device, a pump draws the atmosphere and its aerosols through a filter in order to capture the collected aerosols. At the end of each collection period, the filter is retracted into a pyrolysis furnace where the effluent from the captured aerosols is analyzed, first at ambient (~0ºC) temperature, subsequently heated to 250ºC and then to 600ºC in order to conduct a stepwise pyrolysis. The volatiles vaporize first at the lowest temperature. The more complex, less volatile organic material, and finally higher-temperature organics in the particles are pyrolysed, leaving only more refractory material if any. The pyrolysed products are flushed into GCMS for analysis, thereby providing spectra for each analysis step.

The Descent Imager/Spectral Radiometer (DISR)

The Descent Imager/Spectral Radiometer (DISR) is the optical remote-sensing instrument aboard Huygens. It consists of a set of upward and downward looking photometers, visible and IR spectrometers, a solar aureole sensor, a side-looking imager, and two down-looking imagers: a medium-resolution and a high-resolution imager. It also is equipped with a sun-sensor that will measure the Probe spin rate.

DISR makes measurements in the range 0.3 to 1.7 µm. The scientific objectives of DISR are to study:

- The thermal balance and dynamics of the atmosphere of Titan;
- The distribution and properties of aerosol and cloud particles
- The nature of the surface
- The composition of the atmosphere.

This broad range of scientific objectives is achieved by measuring the brightness of sunlight in Titan's atmosphere with three different fields of views, in several directions and at various spectral resolutions. DISR measures the solar radiation using silicon photodiodes, a 2D silicon charge-coupled-device (CCD) detector and two InGaAs near-IR linear array detectors. The sensor-head is mounted on the outer rim of the Probe, on the equatorial platform. A set of optical fibers feeds light collected by the fore-optics from different directions and in different spectral regions to the appropriate detectors.

Small vanes have been placed on the fore-dome of the Probe to allow it to spin in a controlled manner during the descent. This rotation allows the imagers to scan through 360-degrees and record panoramic pictures. By taking several panoramas during the last part of the descent, it may be possible to infer the Probe's drift (if surface features are visible), hence to derive the wind velocity.

Titan is about 10 AUs from the Sun. The amount of sunlight striking the upper atmosphere is about 1/100th of that at Earth. Atmospheric absorption and scattering further reduces the light reaching Titan's surface by about a factor of 10. A useful comparison is that Titan's equatorial surface illumination during daytime is about 350 times that of nighttime on Earth with a full Moon. While this surface illumination is adequate for imaging, DISR will need to turn on a lamp a few hundred meters above the surface to provide enough light in the methane absorption bands for spectral reflectance measurements. These measurements will provide unique information about the composition of the surface material.

Evaluation of the gas flow around the descent module during the 1 min time-gap between the back-cover separation and the heat-shield release showed a small risk of contaminating DISR's optical windows. In order to prevent contamination of the DISR optics, a protective cover was added to the sensor-head. It will be ejected shortly after the heat-shield is released. Should its release mechanism fail, the cover is provided with optical windows that would still allow measurements with it in place, although with some loss in quality.

Huygens Atmosphere Structure Instrument **(HASI)**

HASI is also a multi-sensor instrument. It measures the atmosphere's physical and electrical properties. Its set of sensors consists of a 3-axis piezo-accelerometer, a 1-axis servo-accelerometer, a coarse and a fine temperature sensors, a multi-range pressure sensor, a microphone, and an electric-field sensor array. The set of accelerometers is specifically optimized to measure entry deceleration for the purpose of inferring the atmospheric structure during the entry.

The electric-field sensors consist of a relaxation probe to measure the atmosphere's ionic conductivity and a quadrupolar array of electrodes for measuring the permittivity of both the atmosphere and of the surface material. In the active mode, it uses the mutual-impedance probe technique for permittivity measurements. In the passive mode, two electrodes of the quadrupolar array are also used as an electric antenna to detect atmospheric electromagnetic waves, such as those produced by lightning.

Several of HASI's sensors require accommodation on booms. The temperature and pressure sensors are mounted on a 15-cm long fixed stub, which is long enough to protrude into the free gas flow. The electrical sensors are mounted on a pair of 60-cm long deployable booms in order to minimize the shielding effects of the Probe body. The capability for processing the radar altimeter surface-reflected signal (the altitude sensor is provided as part of the Probe engineering system), was added to HASI late in the program. This additional function allows it to return information about the surface topography and radar properties below the Probe along the lower part of the descent track.

The Doppler Wind Experiment (DWE)

The primary scientific objective of the Doppler Wind Experiment is to determine the direction and strength of Titan's zonal winds. A height profile of wind velocity will be derived from the residual Doppler shift of the Probe's radio relay signal as received by the Cassini Saturn Orbiter. This will be corrected for all known Probe and Orbiter motion and signal propagation effects. Wind-induced motion of the Probe will be measured to a precision better than 1 m/s starting from parachute deployment at an altitude of ~165 km down to the surface. As secondary objectives, this investigation is also capable of providing valuable information on Probe dynamics (e.g. spin rate and spin phase) during the atmospheric descent, as well as the Probe's location and orientation up to and after impact on Titan's surface.

DWE uses one of the two redundant chains of the Probe-Orbiter radio link [2,6]. It required the addition of two ultra-stable oscillators (USOs) to one of the two channels of the Probe data relay subsystem. The Probe transmitter USO (TUSO) provides a stable carrier frequency for the Probe-to-Orbiter radio link; the Receiver USO (RUSO) aboard the Orbiter provides an accurate reference signal for the on-board Doppler processing of the received carrier signal. The Probe's drift with the wind will induce a measurable Doppler shift in the carrier signal. The wind-induced Doppler shift will add to the other deterministic frequency shifts that are induced in the signal. The strongest source of Doppler is due to the Orbiter-Probe range variation.

The radio relay link channel that is provided with the TUSO and the RUSO is also equipped with the same standard oscillators that equip the other radio relay link channel. It provides an alternative configuration if the performance of either the TUSO or the RUSO would have degraded during the 7-year cruise. Selecting between the DWE USOs (the default configuration) and the standard oscillators will be done during the Probe configuration activity before its release from the Orbiter.

Surface Science Package (SSP)

The SSP consists of a suite of laboratory-type sensors for determining the physical properties of the surface at the impact site and for providing information on the composition of the surface material. The SSP includes a force transducer for measuring the impact deceleration, and sensors to measure the index of refraction, temperature, thermal conductivity, heat capacity, speed of sound, and dielectric constant of any liquid material at the impact site. The SSP also includes an acoustic sounder that is turned on a few hundred meters above the surface for sounding the atmosphere's bottom layer and the surface's physical characteristics before impact. If Huygens lands in a liquid, the acoustic sounder will be used as a sonar to probe the liquid depth. A tilt sensor is included to indicate the Probe's attitude after impact. Although SSP's objectives are mainly to investigate the surface, several sensors will contribute significantly to the studies of atmospheric properties during the whole descent phase.

3. HUYGENS PROBE DESIGN

3.1 Design Overview

The Huygens Probe System [6] consists of two principal elements: i) the Huygens Probe itself, the element that will detach from the Saturn Orbiter and enter in the atmosphere of Titan; ii) the Probe Support Equipment (PSE), the Huygens element that will remain attached to the Orbiter after Probe separation, and will provide the radio relay link functions with the Probe.

The Probe (Fig. 6) consists of two elements: The aeroshell and the Descent Module. The aeroshell is wrapped into a multi-layer thermal protection for the cruise phase. It is made of two parts: the front-shield and the back-cover. The Descent Module comprises two platforms, a fore-dome and an after-cone.

The Descent Module is enclosed in the aeroshell like a cocoon. The aeroshell and the Descent Module are attached to each other by mechanisms at three points. The aeroshell is jettisoned after entry.

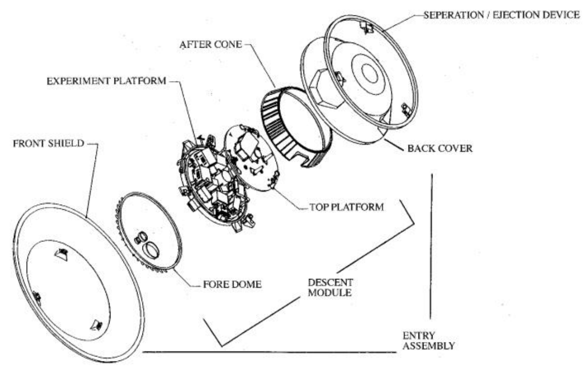

Fig. 6: Exploded view of the Huygens Probe. It weighs 319 kg.

3.2 The entry aeroshell

The front-shield: The 79 kg, 2.7 m diameter, 60-degree half-angle coni-spherical front-shield is designed to decelerate the Probe in Titan's upper atmosphere from about 6 km/s at entry to a velocity equivalent to about Mach 1.5 (~ 400 m/s) by around 160 km altitude. Tiles of "AQ60" ablative material –a felt of phenolic resin reinforced by silica fibres- provide protection against the entry thermal flux up to 1.4 MW/m^2. The shield is then jettisoned and the Descent Control Subsystem (DCSS) is activated to control the descent (via parachutes) of the Descent Module (DM) to the surface. The front-shield supporting structure is a Carbon Fibre Reinforced Plastic (CFRP) honeycomb shell. It was also designed to protect the DM from the heat generated during entry. The AQ60 tiles are attached to the CFRP structure by adhesive CAF/730. Prosial, a suspension of hollow silica spheres in silicon elastomer, is sprayed directly on the aluminium structure of the FRSS rear surfaces, which are expected to experience heat fluxes ten times lower than those to be experienced by the front-shield.

The Back-cover Subsystem: The Back-cover (BC) protects the DM during entry, and carries multi-layer insulation for the cruise and coast. A hole in it ensures depressurisation during Launch and repressurisation during entry. As it does not have stringent aerothermodynamic requirements, it is a stiffened aluminium shell of minimal mass (11.4 kg) protected by Prosial (5 kg). It includes: i) an access door for late integration and forced-air ground cooling of the Probe; ii) a break-out patch through which the first (drogue) parachute is fired; iii) a labyrinth sealing joint with the front-shield, which provides a non-structural thermal and particulate barrier.

3.3 The Descent Control Subsystem (DCSS)

The DCSS controls the descent rate to satisfy the scientific payload's requirements, and to provide the attitude stability to meet the requirements of the Probe-to-Orbiter RF data link and the stability requirements of the descent imager (DISR). The DCSS is activated nominally at Mach 1.5, at about 160 km altitude.

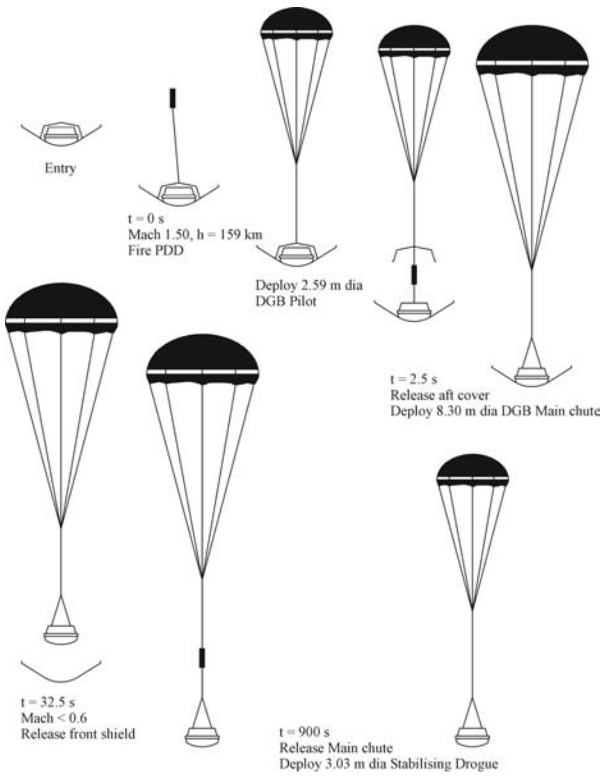

Figure 7: Huygens parachute deployment sequence.

The sequence (Fig. 7) begins by firing the Parachute Deployment Device (PDD) to eject the pilot chute pack through the Back Cover's break-out patch, the attachment pins of which shear under the impact. The 2.59 m diameter Disk Gap Band (DGB) pilot chute inflates 27 m behind the DM and pulls the back-cover away from the assembly. As it goes, the back-cover pulls the 8.30 m diameter DGB main parachute from its container. This canopy inflates during the supersonic phase in order to decelerate and stabilise the Probe through the transonic regime. The front-shield is released at about Mach 0.6. In fact, the main parachute is sized by the requirement to provide sufficient deceleration to guarantee a positive separation of the front-shield from the Descent Module. The main parachute is too large for a nominal descent time shorter than 2.5 h, a constraint imposed by battery capacity, communication geometry between the Probe and the Orbiter, and thermal performances of the DM in Titan's atmosphere. It is therefore jettisoned after 15 min and a 3.03 m diameter DGB stabilising parachute is deployed. All parachutes are made of kevlar lines and nylon fabric. The main and the stabiliser chutes are housed in a single canister on the DM's top platform. Compatibility with the Probe's spin is ensured by incorporating a swivel using redundant low-friction bearings in the connecting riser of both the main and stabiliser parachutes.

The main Huygens design parameters are summarised in Table 3.

Probe Release on 25 December 2005
21-day cost to Titan
Probe wake-up 4h23 min before expected arrival at Titan
Titan Entry: 14 January at 9:00 UTC
Entry corridor: - 65º±3º
Entry velocity: ~ 6100 m/s
Peak deceleration: 100-190 m/s^2
Peak heat flux: 500-1400 kW/m^2
Parachute deployment altitude (mach 1.5): 180-140 km
Descent time: 2h30 ±15 min.
Impact speed: ~ 5m/s
Duration of the radio link with Orbiter: 4h35min
$LiSO_2$Battery energy budget (after entry): 4-7 hours

Table 3: Summary of the Huygens mission parameters

4. HUYGENS PROBE TRAJECTORY

4.1 Entry Trajectory

The entry trajectory main characteristics are shown in Fig. 7.

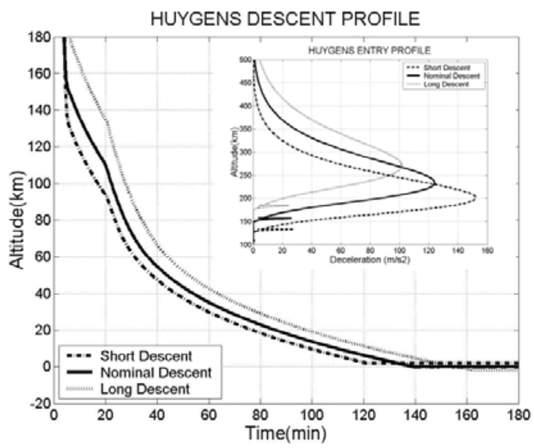

Fig. 7. Huygens Entry and Descent Trajectory

The peak deceleration is expected in the altitude range below 350 km down to 220 km, where Huygens decelerates from about 6 km/s to 400 m/s (Mach 1.5) in less than 2 min. The detection of the entry deceleration peak will be used to set the starting time of the parachute deployment sequence (see Fig. 4).

The entry trajectory has been studied with various tools developed either by Industry or by ESA. Currently all relevant aerodynamical parameters are compiled in the Huygens design aerodynamic database [7].

4.2 Descent Trajectory

At Mach 1.5, the parachute deployment sequence will be initiated. It starts with the firing of a pyrotechnic device that deploys the 2.59 m diameter pilot chute which, in turn, pulls away the aft cover and deploys the main chute. After inflation of the 8.3 m diameter main parachute, the front heat-shield is released so that it falls away from the Descent Module. Then, there is a 30 s delay to ensure that the shield is sufficiently far away to avoid instrument contamination. Now the GCMS and ACP inlet ports open and the HASI booms deploy. The DISR cover is ejected 2 min later. The main parachute is sized to pull the Descent Module safely out of the front-shield. After 15 min, it is jettisoned to avoid a protracted descent, and a smaller, 3.03 m diameter parachute is deployed. The descent will last between 2 and 2½ hours, (see Fig. 7).

4.3 Probe Spin

Huygens is separated from the Orbiter by activation of its Spin-and-Eject device. It imparts a 7 RPM spin to the Probe that provides stability during the coast and the entry.

The main parachute and the stabilizer parachute are linked to the Probe descent module via a swivel mechanism that decouples the Probe spin from that of the parachute.

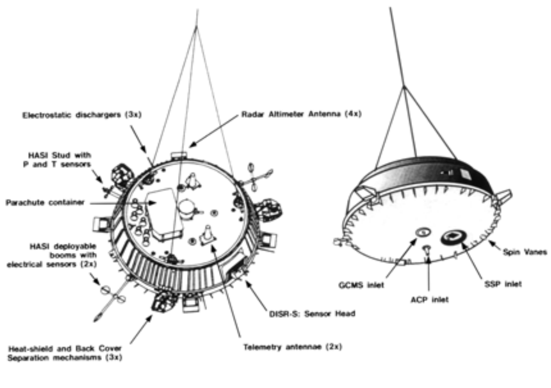

Fig. 8. Perspective views of the Huygens Probe.

During the descent, Huygens´ spin is driven by a set of 36 spin vanes mounted on the bottom part of the foredome (Fig. 8) The expected spin profile during the descent is shown in Fig. 9. The main uncertainties in the predicted spin profile are due to: i) the atmosphere uncertainty and ii) the performance (torque) of the swivel during the descent to provide the azimuthal coverage needed by several sensors.

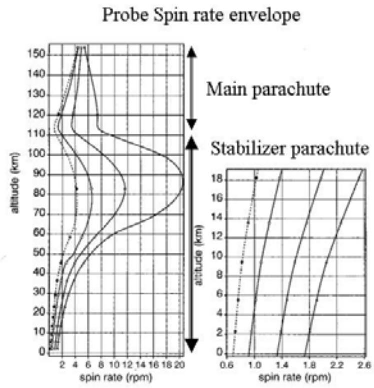

Fig. 9. Huygens Probe spin rate envelope

5. TRAJECTORY RECONSTRUCTION

5.1 Descent Trajectory Working Group (DTWG)

The reconstruction of the probe trajectory is one of the early priorities of the Huygens Science Working Team (HSWT) during the post-flight data analysis. The goal is to derive a reference trajectory as soon as possible in order to allow all instrument teams to process their data with respect to the same trajectory. This task has been assigned to the Descent Trajectory Working Group, a sub-group of the HSWT. The DTWG work started a few years before launch. The reconstruction of the trajectory is based on measurements provided by the payload and also by Probe sensors, such as the system accelerometers and the radar altimeter. The DTWG work is described in [8]. The reconstruction of the probe attitude is also an early priority of the post-flight data analysis phase and a main objectives of the DISR investigation [9].

The HASI accelerometers provide key data for the reconstruction of the entry trajectory. A special effort is being made by the HASI team to analyze and interpret the data sets obtained during in-flight probe checkouts in order to characterize the accelerometer performance, talking into account the Probe system environment and ageing during the 7-year cruise phase [10].

A special effort is being made to test tools developed for the reconstruction of the trajectory. One approach used is based on simulated synthetic data set [11].

5.2 Additional data types

Four unique observations, which were not foreseen during the Probe development, are now being planned. Each observations will contribute in its own way to the reconstruction of the Probe trajectory:

Probe imaging after separation: The post-separation reconstruction of the probe trajectory will be obtained by analysis of the separation dynamics as measured by Orbiter attitude control sensors. The probe trajectory knowledge could be improved by continuing to track the Orbiter after separation. Tracking data could be used to improve knowledge of the pre-separation state vector, satellite ephemeris and satellite constant. A further improvement could be achieved by imaging the Probe from the Orbiter for a few days after separation, thus determining relative separation errors by using optical navigation techniques.

Ground-based tracking of the Huygens Probe during descent: The radio signal from the Huygens Probe will be received using radio tracking stations on Earth as it descends through the atmosphere of Titan. The recording will be used to determine the Doppler shift of the signal and hence the velocity of the Probe in the direction of Earth. These velocity measurements will be used to determine the Titan wind speed as a function of altitude, thereby complementing the Huygens signal measurements by DWE performed along the Probe-Orbiter direction. A similar experiment was performed with the Galileo Probe at Jupiter, the signal Doppler shift being recorded on the Galileo Orbiter and on the Earth [12].

Direct detection of the Huygens radio signal by VLBI: The feasibility of VLBI (Very Long Baseline Interferometry) observations of the Huygens Probe during its descent through the atmosphere of Titan indicate that the observation is feasible [13]. Such data would provide sub-km localization of the probe at a few sec time resolution during the whole descent. An implementation of the observation is currently under study. The complementarity of the VLBI observations with the Ground-based Doppler tracking is under assessment.

Probe entry plume detection from Earth: The peculiar aerothermochemistry in the shock layer of a body entering Titan's methane-rich nitrogen atmosphere produces enough light as to make it possible to detect the "meteor trail" created by Huygens entry. Besides being of scientific value, such observations would also be of enormous public interest [14].

6. HUYGENS MISSION STATUS

Probe in-flight checkout activities: The performance of the various probe subsystems and of the payload has been regularly tested during the bi-annual in-flight checkouts. All payload sensors and subsystems are functioning as expected. (Note that one-shot mechanisms cannot be tested during these checkouts)

A comprehensive test of the Probe-to-Orbiter radio relay was not performed prior to launch. The tests performed during the checkouts indicate that the radio receiver function as expected when receiving the RF signal though the umbilical link. However, a test using NASA's Deep Space Network (DSN) antenna at Goldstone for transmitting to Cassini's HGA a signal mimicking the Probe's signal was performed in Feb. 2000 (PRT#1, in Fig. 2). It uncovered a Huygens radio receiver design fault that, unchecked, would have resulted in nearly complete loss of the data during the Huygens mission.

Huygens Mission recovery: To recover the full Huygens scientific return, significant changes were made to the Cassini/Huygens mission. These changes are documented in the published literature [1,2,3]. The main changes include a Cassini trajectory modification and Huygens on-board software modifications, both in the Probe central computers and in several instrument computers. The last step in the implementation of the recovery mission is planned to take place in mid-December 2003, when the on-board software patches will be loaded and validated on the Huygens computers. This will implement the capability (known as the "preheating" option) to wake-up the probe 4 hours earlier than originally planned at the end of the coast phase.

Pre-separation activities: The main Huygens activities that are planned before separation are:

- Full in-flight engineering demonstration of the Probe-Relay phase (early March 2004);
- Probe checkouts: Late March 2004, mid-July 2004, September and November 2004;
- Probe configuration before separation: 22 December 2004.

Titan atmosphere validation: The Huygens design is sensitive to the atmosphere structure during the entry phase. The Huygens Mission Team is preparing itself to re-assess the performance of Huygens during entry, taking into account the expected new observations of Titan that will be performed by the Orbiter at T0 (a distant flyby at 339000km on 3rd July 2003), and at Ta (a targeted flyby on 26 October), and possibly on Tb (a targeted flyby on 13 December 2004).

An adequate strategy is being put in place to be able to assess the Huygens entry performance in case a significant deviation of the atmosphere of Titan is found with respect to the envelope of the Yelle model including gravity waves. This could lead, for example, to consideration of a slight adjustment of the baseline entry angle, currently set at -65˚, with ±3˚ uncertainty.

REFERENCES

[1] Matson, D.L., Spilker, L.J., and Lebreton, J.-P., , *The Cassini/Huygens Mission to the Saturnian System*, Space Science Reviews, 104:1-58, 2002

[2] Lebreton, J.-P., and D. L. Matson, *The Huygens Probe: Science, payload and Misison Overview,* Space Science Reviews, 104:59-100, 2002.

[3] ESA SP-1177 (ed. A. Wilson), *Huygens: Science Payload, and Misison Overview*, ESA Publication, (1997).

[4] Kazeminejad, B., Lebreton, J.-P., Bird, M.K, and Atkinson D. H., *Titan Wind Effects on the Descent Trajectory of the ESA Huygens Probe*, Proc. ESLAB Symposium, "Earth-Like planets and Moons", ESTEC, Noordwijk, 3-8 June 2002 (ESA SP-415, October 2002)

[5] Russell, C. (ed), *The Cassini-Huygens Mission, Overview, Objectives and Huygens Instrumentarium,* Vol. 104 Nos 1-4 (2002)

[6] Clausen, K. C., Hassan, H., Verdant, M., Couzin, P., Huttin, G., Brisson, M., Sollazzo, C., and Lebreton, J.-P., The Huygens Probe System Design, Space Science Reviews, 104:155-189, 2002.

[7] *Huygens design aerodynamic database*, to be published.

[8] *Kazeminejad, B., and Atkinson D. H., The ESA Huygens Probe Entry and Descent Trajectory Reconstruction* (this issue)

[9] Rizk B., et al., *Recovering the Attitude of the Huygens Descent Module using DISR Data* (this issue)

[10] Zarnecki J.,, Ferri F., Hathi, B., Leese, M.R., Ball, A.J., ColombattiG., and Fulchignoni, M., *In-Flight Performance of the HASI Servo Accelerometer and Implications for Results at Titan*, (this issue)

[11] Pérez Ayúcar, M., Witasse, O., Lebreton, J.-P., Kazeminejad, B., and Atkinson, D.H*, A Simulated Dataset of the Huygens Mission,* (this issue)

[12] Folkner, W.M., et al., *Ground-Based Tracking of the Huygens Probe During the Titan Descent* (this issue).

[13] Pogrebenko, S. V., et al., *VLBI Tracking of the Huygens Probe in the Atmosphere of Titan* (this issue)

[14] Lorenz, R., *An Artificial meteor on Titan?,* Astronomy and Geophysics, 2002