Cassini/Huygens: Heavily Instrumented Flight Systems Approaching Saturn and Titan[1]

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Abstract—The Cassini and Huygens flight systems are described including capabilities, launch, flight path, mission science objectives, and instruments. Interplanetary cruise, Saturn arrival, and science-tour operations are also discussed, including use of JPL's worldwide Deep Space Network for two-way communications. Launched 15 October 1997, Cassini/Huygens will arrive at the Saturnian system on 1 July 2004. The Cassini Orbiter begins a four-year tour of the ringed gas giant, and the Huygens Probe descends through Titan's dense atmosphere on 14 January 2005.

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1. INTRODUCTION

Cassini/Huygens, an Orbiter/Probe spacecraft combination, is en route to Saturn. The Orbiter is named for the seventeenth century Italian/French astronomer Jean Dominique Cassini, who correctly identified the nature of Saturn's rings as swarms of moonlets too tiny to be seen individually, discovered the prominent gap in the rings that now bears his name, and three of Saturn's icy satellites. The probe destined for Saturn's moon Titan is named for Christiaan Huygens, the seventeenth century Dutch astronomer who discovered Titan and the true shape of Saturn's rings.

Saturn is the farthest of the planets known to our ancient ancestors. Today, it is the farthest of the planets to be the subject of an orbiting spacecraft.

This paper describes the Cassini/Huygens spacecraft and mission in a way that highlights what the author considers their most remarkable features. It concludes with a note on a perspective.

Cassini/Huygens is a cooperative project of NASA, the European Space Agency, and the Italian Space Agency. The Jet Propulsion Laboratory, a division of the California Institute of Technology, manages the Cassini/Huygens mission for NASA's Office of Space Science, Washington, D.C.

2. THE CASSINI ORBITER

The Spacecraft and Its Attitude Control

A 2442 kg spacecraft (dry mass) 6.6 m in length is freefalling towards encounter with the vast Saturnian system. It monitors its own attitude in three axes using celestial and/or inertial references. Based on high-level commands, it controls its attitude to an accuracy of 1 mrad either by firing pairs of 0.9 N thrusters or by trading angular momentum between the whole spacecraft body and its electrically

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driven, reversible reaction wheels (normally three; there is an articulated spare). The dual-redundant flight computer of the Attitude and Articulation Control Subsystem (AACS) maintains knowledge of the body attitudes required for all spacecraft tasks, such as communicating with Earth or making science observations, and it propagates this knowledge out in time. AACS's inertial reference units are quartz hemispherical resonators, with no moving parts other than induced vibration. They sense changes in attitude by tracking the precession of vibratory nulls around the rims of their "wine-glass" resonators. "Articulation" refers to AACS's control of the main rocket engines' gimbals and its ability to orient the spare reaction wheel.

AACS is one of a dozen engineering subsystems and 12 science instrument subsystems on the Cassini Orbiter. The Huygens Probe, itself a complete flight system, has another set of engineering subsystems and six science experiments.

Propulsion

The Cassini Orbiter's propulsion subsystem includes two separate plumbing sets: (1) one primary and one backup main engine take hypergolic fuel and oxidizer, mono-methyl hydrazine, and nitrogen tetroxide from big centrally located tanks which together, at launch, held 3123 kg (note this was more mass than the spacecraft hardware; 2163 kg remain today), and (2) 16 attitude control thrusters (two redundant sets of 8) burn hydrazine in their electrically heated catalyst chambers, delivered under pressure from a small side-mounted tank (12 kg have been used to date, with 120 kg remaining). The primary or the backup gimbaled 445 N main engine will execute a 95-minute nominal burn to achieve Saturn orbit onjection (SOI) on 1 July 2004. On-board accelerometers will determine the burn's exact cutoff in real time based on actual energy achieved. The main engine has been used in flight for ten minor course adjustments plus one 90-minute Venus-targeting burn. They are normally protected from meteoroids in flight by a retractable hemispheric pleated shield that is stowed (opened) whenever the main engines are to be operated.

Command and Data

The Cassini Orbiter's Command and Data Subsystem (CDS) communicates with all the other onboard subsystems over a dual-redundant MIL-STD-1553 bus interface system. The redundant CDS electronic assembly incorporates two IBM engineering flight computers that can send commands to, and request data from, the spacecraft subsystems and instruments via Bus Interface Units and Remote Engineering Units. CDS's two 2-Gbit Solid-State Recorders (SSRs) store telemetry data for later downlink, as well as images of

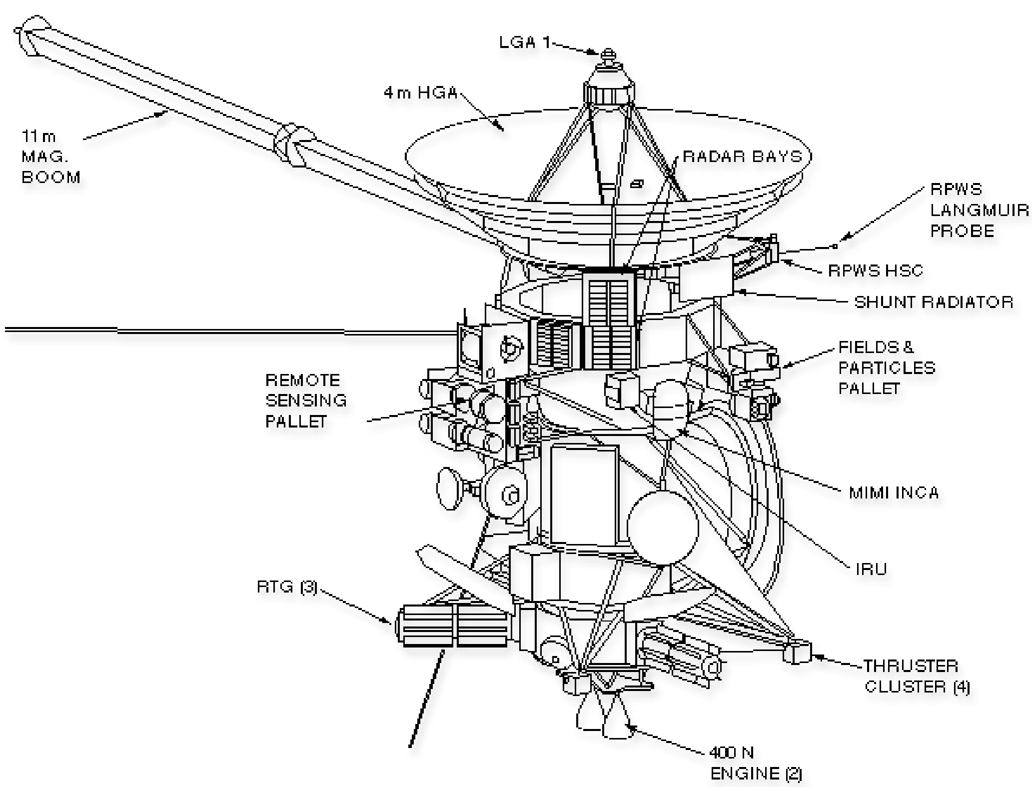


Figure 1 - The Cassini Orbiter with attached Huygens Probe visible mid right

flight software for CDS and other subsystems and science instruments.

Autonomy—The hours required for round-trip communication during the mission dictate that the spacecraft be able to autonomously detect a range of faults, and manage redundant hardware and software, in order to protect the scientific mission. Both the CDS and the AACS computers run fault protection routines, constantly checking to be sure no safety constraints are being violated. For an example of a fault-protection routine, consider the Command Loss Timer. Commands from Earth set the value of the timer, which today is 950,000 seconds, about eleven days. Each time any command is received from Earth, the receiving CDS (CDS-A, CDS-B, or both) begins counting down from that value. If one CDS were ever to get to zero, the program would "assume" that no commands had been received from Earth; therefore, something in the communications path must be malfunctioning. One of its autonomous actions after that point is requesting CDS to power the operating telecommunications equipment off and the backup equipment on so it can begin receiving commands from worried engineers.

One possible CDS response to some detected faults is spacecraft "safing." Safing is a programmable, pre-set configuration that includes discontinuing the processing of the "normal" command sequence, shutting off nonessential electrical loads, turning to a thermally safe attitude while keeping sunlight out of the instruments' apertures, and waiting for further instructions, possibly switching from the High-Gain Antenna (HGA) to a Low Gain Antenna (LGA) for communications. To date the spacecraft has entered safing three times, all for reasons subsequently understood. Each time it has been reconfigured to normal operations within about a week.

Flight Software

Saturn-tour versions of flight software for both AACS and CDS are currently finishing ground testing. They will be installed aboard the Cassini flight system and tested extensively early in 2003. Cassini's cruise of nearly seven years provided the time required for the extensive task of coding and testing Saturn tour versions of flight software for AACS and CDS, and also flight software for many of the science instruments' computers.

A Hard-wired Problem Solved—Most of the flight code aboard the Huygens Probe resides in read-only memory, so it cannot be updated. During an in-flight probe communications simulation in February 2000, it was discovered that the originally planned rate of closure between Orbiter and Probe would cause an unacceptably large Doppler shift in Huygens' received uplink while executing its mission in Titan's atmosphere. There was no way to merely uplink an appropriate fix. The early stages of arrival in the Saturnian system were therefore redesigned while preserving plans already worked for the remainder of Saturn Tour, so that the Cassini Orbiter will overfly Titan during Huygens' mission at an altitude of 60,000 km instead of the originally planned 1200 km. Given the reduced closure rate with this new geometry, the Probe receiver equipment aboard the Orbiter

will now be able to acquire all the telemetry symbols Huygens can send.

Telecommunications

One of Cassini's two Deep Space Transponders (DSTs) receives the 8 GHz (X-band) uplink from the home planet. Commands for CDS to store or process, and ranging tones to send back to the navigators, are demodulated from the uplink's subcarriers when present. The DSTs routinely use the received signal as a highly stable frequency reference for generating a downlink signal phase-coherent with the uplink. A 20 W travelling wave tube (TWT) amplifies that signal for the long trip home. Upon arrival at Earth, it is routinely frequency counted. Once Earth's motions are subtracted out, comparison of the downlink and uplink frequencies provides Doppler shift data useful for navigation that typically yields a velocity determination to an order of millimeters per second.

Cassini's DSTs modulate the X-band downlink with ranging tones and telemetry. The telemetry, downlinked at selected rates to a maximum of 140 kbits/s from Saturn, comprises both science data from the instruments, and health and safety data. Cassini/Huygens makes over 13,000 different on-board measurements, or "telemetry channels," to downlink routinely.

The X-band link is also used in Radio Science remote sensing, for example ring or atmosphere occultation experiments, and for satellite mass measurements via Doppler shift analysis. Cassini also carries an S-band solid-state transmitter and a Ka-band TWT that are dedicated Radio Science instruments. They provide unmodulated downlink carrier tones that can be made phase-coherent with an uplink, if desired. A downconverter translates any received Ka-band uplink tone for the DSTs to process.

Cassini can also receive S-band radio signals, but only with the two receivers of the Huygens Probe Support Equipment designed for use during the Probe's mission in Titan's atmosphere. S-band uplink from Earth is used only to test the Probe Support Equipment receivers.

The Cassini Orbiter's 4 m aperture HGA subsystem serves all these functions. It also employs a multiple-feed system to provide a steerable beam for the Radar experiment's Ku-band transmission and reception. The Radar experiment is designed to actively acquire synthetic aperture Titan imaging data and Titan altimetry data, and to passively acquire radiometry data from many targets while in the experiment's receive-only mode. It has already been used in flight in the latter mode, taking radiometry data from both the Sun and Jupiter for calibration. One of two LGAs can be commanded to serve the X-band telecommunications functions instead of the HGA when the need arises for a nearly omnidirectional capability, albeit at low data rates. Only five bits per second can be received from an LGA at Saturn's distance.

Electrical Power in the Outer Solar System

With no moving parts, the three Radioisotope Thermo-electric Generators (RTGs) together provide 0.767 kW of electrical power for the spacecraft today. At launch their combined output was 0.875 kW, and by end of mission this level will have decreased to 0.687 kW, owing to the decay of plutonium-238 within ceramic pellets protected by multiple high-strength enclosures. This relatively rapid (87-year half-life) decay provides heat to drive banks of silicon/germanium thermocouples. Electrical distribution is switched and load protected by a 192-channel Solid-State Power Switch under control of commands from the CDS. A special distribution bank equipped with high-value capacitors was employed to fire various pyrotechnic devices, deploying a handful of mechanical assemblies after launch

Thermal Control

The RTGs, as well as the various electrical loads (including electric heaters), are an important source of thermal energy for the spacecraft. Blankets of reflective multilayer insulation control heat retention and rejection while also providing a measure of protection from impactors. Autonomous bi-metallic mechanisms open mechanical louvers in a number of locations to release thermal radiation from the spacecraft, and they close to retain it when needed.

3. THE HUYGENS PROBE

Built for the European Space Agency by an industrial consortium led by Aerospatiale (now Alcatel), the Huygens Probe flight system comprises two principal elements: the 318 kg Probe that enters Titan's atmosphere, and 30 kg of Probe Support Equipment that remains attached to the Orbiter.

Structure

The Huygens Probe's structure consists of two aluminum honeycomb platforms within an aluminum shell, connected to its front heat shield and aft cover with pyrotechnically operated release mechanisms. The lower platform carries electrical subsystems and six science experiments. The upper platform carries stowed parachutes and antennas for communication with the Orbiter.

Electrical Power

Prior to separation from the Orbiter, the Probe takes electrical power via an umbilical for its semi-annual checkouts while the batteries remain isolated. After separation, the Orbiter continues to power the Probe Support Equipment, but the Probe itself draws from five lithium sulphur-dioxide 7.6 Ah batteries on board. Only a timer runs during the three weeks spent coasting to Titan, and higher current is only required while descending through the atmosphere. The loss of one battery would not prevent a complete mission. If the Probe survives impact with the surface, the batteries can provide up to about 30 minutes of additional operation.

Separation

Three pyro-nuts will fire on 25 December 2004, releasing the Huygens Probe from the Cassini Orbiter under the action of three 500-N stainless steel springs. Roller-guides following a helical track impart a 7.29 rpm spin to the Probe as it leaves the Orbiter at 0.3367 m/s. The spin henceforth serves to preserve the Probe's attitude, set carefully and checked by the Orbiter before release. The Probe will attain its lowest temperature condition following release. A number of radioisotope heater units, each generating 1 W of heat, prevent any of its equipment from falling below safe limits.

Control and Communication

A triply redundant mission timer switches the Probe "on" just prior to atmospheric entry, and then the Command and Data Management Subsystem controls activation of the deployment mechanisms during descent. It commands the engineering subsystems and science instruments, and also distributes a descent data broadcast to them, providing a timeline of conditions to which the instruments can then schedule mode changes and operations. It collects science and housekeeping data to forward to the Orbiter during descent via the Probe Data Relay Subsystem whose two redundant S-band transmitters, each with its own antenna, sends telemetry in two similar (but not identical) telemetry streams, one delayed four seconds with respect to the other to minimize data loss in case there are interruptions.

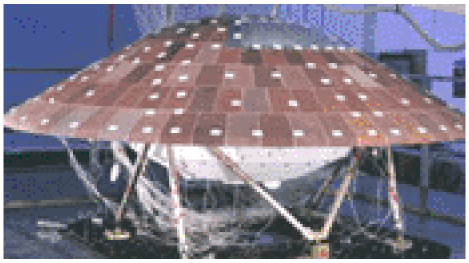


Figure 2 - The Huygens Probe

Atmospheric Entry

While the Orbiter is approaching Titan, the Huygens Probe enters the satellite's hazy, dense nitrogen atmosphere at 6.1 km/s, experiencing up to 16 g as it slows within 3 minutes to about 400 m/s. The front shield protects the Probe from the heat of a plasma shock approaching 12,000° C, twice the temperature of the Sun's photosphere. Silica tiles like those used on the Space Shuttle cover the front shield, their thickness calculated to ensure the structure will not exceed 150° C. A silica-foam clad aft cover reflects heat radiating from the Probe's wake. The mass of these thermal protection components comprise almost a third of Huygens' mass.

Descent

Around an altitude of 160 km when, based upon data from its accelerometers, the Probe computes its velocity to be Mach 1.5, its Descent Control Subsystem deploys a 2 m diameter pilot chute, pulling off the Probe's aft cover. As it goes, it in turn pulls out an 8.3 m main parachute that slows the Probe to Mach 0.6 in about 30 seconds. The front heat shield separates at this time (this chute's size was selected to guarantee positive shield separation). The Probe descends slowly for about 15 minutes while initial scientific measurements are made and radioed to the Cassini Orbiter. The main parachute, too large for the 2.5 hour descent constraint imposed by the Probe's batteries, separates and releases a 3 m stabilizer chute that allows the Probe to conduct its atmospheric experiments and then impact the surface at about 7 m/s. All three parachutes are a disk gap band type made of nylon fabric with kevlar lines. The Probe has 36 external vanes to impart a spin during descent, while a swivel with redundant low-friction bearings ensures parachute lines do not tangle.

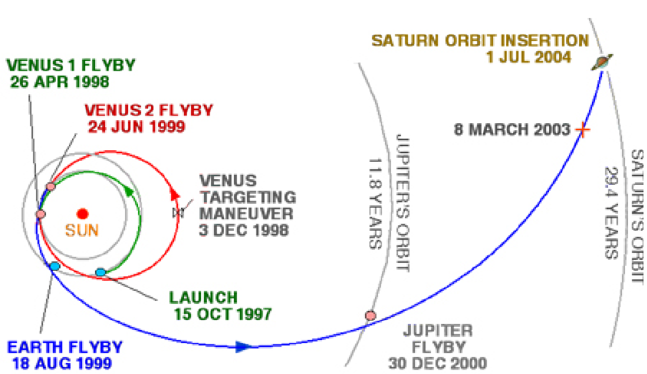


Figure 3 – Interplanetary flight path

4. Interplanetary Flight Path

Even though Cassini/Huygens employed the United States' most capable expendable launch vehicle—a 15 MN Titan-IVB with its restartable cryogenic-hydrogen-and-oxygen-fed Centaur upper stage—four planetary flybys were needed to attain the energy to reach Saturn, so "high" in the well of solar gravitation. In fact, launch sent Cassini/Huygens inward toward the Sun for a Venus flyby rather than outward toward Saturn.

Gravity Assist—Each planetary flyby provided a substantial increase in the spacecraft's Sun-orbital energy at the expense of the planet's own. This is not analogous to "sling-shot" mechanics, as sometimes heard. The exchange occurs because both the planet and the spacecraft attract one another gravitationally while orbiting the Sun: flying behind a planet in its solar orbit, the spacecraft tugs on the planet from behind to make it lose energy, as the planet imparts a good measure of its own orbital momentum to the spacecraft. From the planet's point of view, the spacecraft departs with no net energy gain, but from the Sun's point of view, the exchange affects the massive planet's orbit very little, while benefitting the spacecraft substantially.

Science en route—Originally, Cassini's budget permitted neither the planning, the command sequence development, nor the DSN resources needed to carry out any scientific investigations during planetary flybys. Once the science community realized it had a healthy, stable, well-instrumented platform cruising by three planets, however, plans were modified with existing funds to take at least some data at Venus, Earth, and Jupiter. In fact, the Jupiter encounter coincided fortuitously with observations from different ranges by Galileo in Jovian orbit, and from Earth by the orbiting Hubble Space Telescope and ground-based radio telescopes. Jupiter also provided a good exercise in planning and executing observations for the worldwide ground crew.

Asteroid Belt Crossing—The combined Cassini/Huygens counted as the seventh spacecraft crossing of the main asteroid belt. There were no known asteroids near the flight path, but Cassini did acquire unique images and spectral signatures of the 15 to 20 km diameter asteroid 2685 Masursky from a distance of 1.6 million km on 23 January 2000.

Arrival—Cassini/Huygens reaches Saturn's orbit at the aphelion of the spacecraft's solar orbit, of course, so it is moving at the lowest velocity of its entire flight, relative to the Sun. From there, Saturn sweeps along in its own solar orbit and pulls gravitationally on Cassini/Huygens. The spacecraft passes through the ring plane on the way in at a radius known to be swept free of most material by resonant gravitational interaction with an icy satellite. The SOI main-engine burn is scheduled to be mostly completed before reaching the closest point to Saturn, giving priority to science observations of the atmosphere and rings, even though this nonoptimal orbit injection will cost additional propellant. (The 95-minute nominal Saturn orbit injection burn will actually continue 6 to 9 minutes past periapsis.)

The Right Link—In November 2002 NASA, JPL, and Cassini Program management arrived at the decision for the spacecraft to link with Earth during SOI via carrier signal from an LGA, rather than a signal from the HGA. This scheme will provide Doppler data during the operations immediately surrounding SOI. The HGA, while providing more realtime status data via telemetry as well as Doppler, would have required excessive propellant use because the attitude constraint of keeping HGA on Earth, instead of keeping the main engine on the velocity vector, would mean a longer injection burn. Main engine propellant is, of course, a coveted resource to be preserved for orbit trim maneuvers during a possible extended mission if the spacecraft remains healthy past the end of prime mission in 2008.

5. Flight Operations

Using the Deep Space Network

Cassini is one of more than 40 users currently competing to schedule the resources of JPL's Deep Space Network (DSN) which comprises three Deep Space Communications Complexes, one in California's Mojave Desert near Barstow, one in Spain near Madrid, and one in Australia near Canberra, and a control center at JPL in Pasadena, California. Tracking requirements are estimated years ahead, and then resource schedules are negotiated several weeks in advance in a best-efforts attempt to meet requirements. The DSN resources Cassini routinely uses at all three complexes include the 34 m and 70 m aperture radio telescopes, called Deep Space Stations, equipped with cryogenically cooled maser and FET low-noise amplifiers. Schedule negotiation also includes additional ground equipment such as specific closed-loop receivers, transmitters, telemetry strings, open-loop Radio Science recorders, and ground-communications equipment. This scheduling process must dovetail precisely with Cassini's process of developing sequences of commands, since the command sequences executing aboard for weeks at a time will determine when the spacecraft's HGA points to Earth for communications. During the Saturn tour, there will be one DSN tracking period per day, varying in length from about 8 to 12 hours, while CDS plays back telemetry data from the SSRs. At the same time, additional command sequences and flight software images need to be uplinked and verified, and navigation and radio science data can be acquired.

Real Time Staffing

All DSN tracking periods are staffed by at least one Cassini Program person to help manage real time interactions with the DSN, keep an eye on spacecraft health and safety, and ensure proper data capture, flow, storage, and integrity. Additionally and on various schedules, representatives of the spacecraft subsystems and science instruments may choose to watch data in real time and/or query data from the JPL repositories at their convenience, according to their own needs. Many are working at their own institutions, making use of dedicated communications lines and the Internet for secure data communications.

A New Network

Cassini/Huygens' operational tracking during cruise has been increasingly accompanied by testing and implementation of sweeping new systems in the DSN. The Network Simplification Project is streamlining and consolidating all DSN's highly complex functions to simplify the process of configuring them for and operating them during tracking support while bringing them into compliance, where appropriate, with the standards of the Consultative Committee for Space Data Systems (CCSDS) an international voluntary consensus organization of space agencies and industrial associates. Cassini operations people are in a position to help test and validate these new DSN systems, and we expect to benefit from the reduced operational complexity.

6. Science Objectives and Experiments

Objectives

Cassini/Huygens' specific scientific objectives are numerous for the investigation of Saturn, its atmosphere and interior, its ring system, its magnetosphere, and its satellites, but these objectives may be briefly categorized as follows:

- *Saturn's atmosphere:* Determination of its composition, winds, clouds, structure, diurnal variations, heat flux, and electrical activity

- *Saturn's rings:* Determination of the gravitational, viscous, erosional, and electromagnetic processes responsible for their structure, their chemical makeup and size distribution, relationships with embedded and external moons, and interactions with Saturn's magnetosphere, ionosphere, and atmosphere

- *Saturn's magnetosphere:* Determination of the field shape and orientation, its current flow and charged particle makeup and trajectories, interactions between charged particles and radio waves, interactions among magnetosphere and solar wind, the icy satellites, Titan's atmosphere/ionosphere, and with the rings

- *Saturn's icy satellites:* Determination of their general characteristics, geologic histories, processes of surface and subsurface change, makeup and distribution of surface materials, especially dark material like that on the leading hemisphere of Iapetus, interactions with magnetosphere and rings, and constraints on their internal structure and makeup

- *Titan:* Determination of the makeup and behavior of the atmosphere, ionosphere, the atmosphere's isotope ratios, and the surface characteristics

Additional science objectives are addressed during that portion of Cassini's cruise between Jupiter and Saturn.

- *Gravitational Wave experiment:* Search for low frequency gravitational waves crossing the solar system

- *Superior conjunction experiment:* Measurement of solar general relativistic effects, as well as the density and the dynamics of the solar corona

Experiments

Gravitational Wave—At spacecraft opposition, the noisy solar plasma background is well out of the way so the Radio Science Team can conduct a Gravitational Wave experiment, the first ever to employ Ka-band and X-band coherent Doppler observations in the search for direct evidence of gravitational radiation predicted by General Relativity, and which has not yet been observed. During the 40-day round-the-clock experiment, the spacecraft is kept as quiet and stable as possible, and in constant communication with Earth. Thruster firings are banned, and the reaction wheels maintain a steady, stable attitude. Even small motions, like the Cassini Plasma Spectrometer's "windshield-wiper" aperture sweeping, is quelled, because its subtle effects show up in the (now prime science) Doppler data. The Gravitational Wave Experiment is repeated three times prior to Saturn arrival.

Superior Conjunction—When the spacecraft is around on the other side of the Sun, that is, during superior conjunction, the Radio Science Team has more opportunities for experimentation. The general relativistic effects of the Sun are measured to new levels of precision, and the solar plasma can be actively probed, again using the Ka-band and X-band links.

Engineering Experiment—A superior conjunction follows close on the heels of SOI (see Table 1). Concurrent with the superior conjunction science experiments, Cassini's telecommunications experts carry out engineering experiments to characterize the performance and extinction of the spacecraft's two-way radio link in the solar corona during cruise, the better to plan post-SOI communications strategies. Results so far have shown consistently that the X-band command link is unaffected down to about 2 degrees Sun-Earth-Probe angle; then it drops to about a 10% command acceptance rate at 1 degree separation.

Huygens Probe at Titan—Descending through Titan's atmosphere, Huygens' Atmospheric Structure Instrument reports on atmospheric pressure, temperature, and density; the atmosphere's electrical properties; and turbulence. Its Gas Chromatograph and Mass Spectrometer, and its Aerosol Collector and Pyrolyser report on gaseous and suspended constituents, and will measure the surface composition. The Descent Imager and Spectral Radiometer observes clouds and Titan's surface looming up, even illuminating it with a lamp near touchdown. The Doppler Wind Experiment characterizes atmospheric currents on the way down, employing Ultra-Stable Oscillators as reference signal sources to provide for accurate measurement of the Doppler shift in the Probe-Orbiter RF link. The Surface Science Package determines whether the surface is solid or liquid, and the surface roughness. An accelerometer will record the deceleration profile at impact, indicating surface hardness. If the surface is liquid, a sounder will measure the speed of sound in the "ocean." Other sensors will measure its density, temperature, refractive index, thermal conductivity, heat capacity, and electrical permittivity.

TABLE 1 - CASSINI/HUYGENS MISSION INFORMATION

Launch date:	15 October 1997
Launch energy, C3:	16.6 km^2/sec^2
Venus-1 gravity-assist flyby date:	26 April 1998
Venus-targeting maneuver date:	3 December 1998
Delta-V from this maneuver:	450 m/sec
Venus-2 gravity-assist flyby date:	24 June 1999
Earth gravity-assist flyby date:	18 August 1999
Asteroid belt entry (2.2 AU*) date:	11 December 1999
Asteroid Masursky observation date:	23 January 2000
Asteroid belt exit (3.3 AU) date:	12 April 2000
Jupiter gravity-assist flyby date:	30 December 2000
Total boost from planet flybys:	21.44 km/sec
Propulsive maneuvers to date:	11
Cumulative delta-V of these:	570.521 m/sec
(includes Venus targeting burn of	449.962 m/sec)
Heliocentric range, 8 March 2002:	1,222,632,143 km
Phoebe encounter date:	11 June 2004
Inbound ring plane crossing date:	1 July 2004
Inbound ring plane crossing location:	Gap at 2.68 S. radii (between F and G rings 158,500 km from Saturn center)
Saturn orbit insertion date:	1 July 2004
Delta-V at orbit insertion:	622 m/sec
Superior conjunction date:	8 July 2004
Titan flyby A date:	26 October 2004
Titan flyby B date:	13 December 2004
Huygens Probe release date:	25 December 2004
Huygens Mission (Titan C) date:	14 January 2005
End of mission as currently funded:	30 June 2008
Cost of development, construction, and 11 years of operation (including launch vehicle):	$3.2 billion.

*One Astronomical Unit (AU) = average Sun-Earth distance, approximately 150 x 10^6 km

Extensive Orbiter Science—For at least three and a half years after Huygens' brief mission, the Cassini Orbiter's dozen scientific experiment subsystems will carry out in-depth investigations of every aspect of the Saturnian system.

For the most part, the Cassini Orbiter's science experiments are not atypical of those found on other planetary spacecraft such as a Galileo or a Voyager, but they are incrementally improved and optimized for duty in the Saturnian system. Among the new capabilities carried aboard the Cassini Orbiter are MIMI, the Magnetospheric Imaging Instrument that can, as the name implies, acquire images of a planetary magnetosphere. Cassini's Radio Science Experiment includes the first use of a coherent Ka-band link capability.

Cassini is instrumented to make observations throughout the electromagnetic spectrum, including remote optical sensing, as well as directly sensing and measuring fields and incident particles. A brief description of the Cassini Orbiter's complement of science instruments follows.

Optical Remote Sensing

Pointing the optical remote sensing instruments requires moving the whole spacecraft, because they are affixed to the body, on the +X side of the spacecraft, grouped together on the Remote Sensing Pallet (RSP). Figure 1 shows the RSP on the whole spacecraft. Each of the optical instruments has a radiator facing deep space that connects thermally with the instrument's electronic sensor to keep it cold for optimal performance. Also mounted on the RSP are the two Stellar Reference Units that supply celestial reference for the AACS. These are visible in Figure 3, with their apertures facing toward the left with the radiator panels.

VIMS—The Visual and Infrared Mapping Spectrometer is visible in Figure 3 at the top of the RSP, with one large infrared aperture above and one small visible light aperture below, just above ISS. VIMS is a pair of imaging grating spectrometers designed to measure reflected and emitted radiation from atmospheres, rings, and surfaces over wavelengths from 0.35 to 5.1 μm to determine their compositions, temperatures, and structures.

UVIS—The Ultraviolet Imaging Spectrograph is visible on the right side of Figure 3. UVIS is a set of detectors that measure ultraviolet light reflected or emitted from atmospheres, rings, and surfaces over wavelengths from 55.8 to , distribution, aerosol content, and temperatures.

Figure 3 –Remote sensing pallet

ISS—The Imaging Science Subsystems is visible in the middle of Figure 3 with two apertures. ISS consists of a wide angle camera (the larger aperture in Figure 3), with angular resolution of 60 μrad per pixel, and a narrow angle camera, with angular resolution of 6.0 μrad per pixel. The sensors are 1024 x 1024 CCD arrays.

CIRS—The Composite Infrared Spectrometer is visible at the bottom of Figure 3. The CIRS instrument consists of dual interferometers that measure infrared emission from atmospheres, rings, and surfaces over wavelengths from 7 to 1000 μm to determine their composition and temperatures.

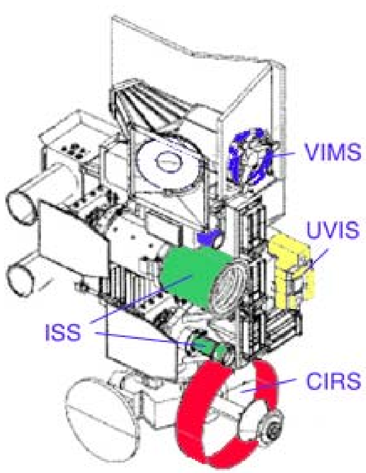
Microwave Remote Sensing

Radar—The Cassini Radar uses a five-beam Ku-band antenna feed assembly associated within the spacecraft HGA (see Figure 1) to direct radar transmissions toward targets, capture the reflected radar signals and blackbody radiation from targets, for investigation of Titan's surface, and other bodies (rings, icy satellites) as conditions permit. Cassini Radar acquires synthetic aperture imaging, altimetry, and radiometry data.

RSS—The Radio Science uses the spacecraft X-band communication link, as well as S-band downlink and Ka-band uplink and downlink, to study the compositions, pressures, and temperatures of atmospheres and ionospheres, radial structure and particle size distribution within rings, and body and system masses, and to search for gravitational waves.

Direct Sensing of Fields, Particles, and Waves

Of the direct-sensing instruments, three can move their own apertures through a limited range as described below. The direct-sensing instruments sense and report on phenomena incident upon them. Four are mounted on the Fields and Particles Pallet to the side of the Cassini Orbiter spacecraft bus, and four are mounted separately. Figure 1 shows most



of these on the whole spacecraft.

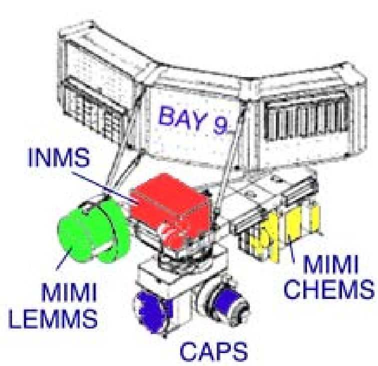


Figure 4 –Fields and particles pallet

INMS—The Ion and Neutral Mass Spectrometer is visible in the middle of Figure 4. The INMS instrument is intended to measure positive ion and neutral species composition and structure in the upper atmosphere of Titan when the spacecraft trajectory brings it within reach of its uppermost atmosphere, as well as in the magnetosphere of Saturn, and to measure the positive ion and neutral environments of Saturn's icy satellites and rings.

MIMI LEMMS—The Magnetospheric Imaging Instrument Low Energy Magnetospheric Measurements System is visible in the left of Figure 4. It measures low- and high-energy proton, ion, and electron angular distributions. The LEMMS head is mounted on a scan platform capable of 180° rotations.

CAPS—The Cassini Plasma Spectrometer is visible at the bottom of Figure 4. CAPS measures the flux of ions as a function of mass per charge, and the flux of ions and electrons as a function of energy per charge and angle of arrival relative to the instrument.

MIMI CHEMS—The Magnetospheric Imaging Instrument Charge Energy Mass Spectrometer is visible in the lower right of Figure 4. It measures the charge state and composition of ions in the most energetically important portion of the Saturnian magnetospheric plasma.

MIMI INCA—The Magnetospheric Imaging Instrument Ion & Neutral Camera is mounted on the minus-Y side of the Cassini Orbiter spacecraft below the bus (see Figure 1). It makes two different types of measurements. It obtains with very high sensitivity the three-dimensional distribution, velocities, and rough composition of magnetospheric and interplanetary ions for those regions in which the energetic ion fluxes are very low. It also obtains remote images of the global distribution of the energetic neutral emission of hot plasmas (particles expelled when ions and electrons combine along magnetic field lines) in the Saturnian magnetosphere, measuring the composition and velocities of those energetic neutrals for each image pixel.

MAG—The Dual Technique Magnetometer instruments are mounted on an 11-m-long fiberglass boom on the +Y side of the Cassini Orbiter spacecraft above the bus. Boom mounting serves to isolate the sensors from noise generated within the spacecraft. MAG determines the planetary magnetic fields and the dynamic interactions in the planetary environment. "Dual technique" refers to one vector/scalar helium magnetometer mounted at the boom's far end, and one fluxgate magnetometer mounted mid-boom.

RPWS—The Radio & Plasma Wave Science experiment has three 10-m-long antennas extending from the +Y side of the Cassini Orbiter spacecraft below the bus, just below the magnetometer boom. It also has a search coil and the Langmuir probe mounted on the minus-X side above the spacecraft bus. RPWS measures the electric and magnetic fields and electron density and temperature in the interplanetary medium and planetary magnetospheres.

CDA—The Cosmic Dust Analyzer instrument is mounted near the +Y side of the Cassini Orbiter spacecraft below the bus, between the Huygens Probe support and the RPWS antennas. It provides direct observations of particulate matter in the Saturnian system to investigate the physical, chemical, and dynamical properties of these particles, and to study their interactions with the rings, icy satellites, and magnetosphere of Saturn.

7. CONCLUSION

It is an immense and intricate task to extend our human senses a thousand million miles from home. What is gained by doing so, with the Cassini Orbiter and the Huygens Probe, is more than knowledge of our “back yard” in the solar system, though this represents quite a gain in itself, to offer future generations. Studying Saturn’s ring system can teach something basic about the mechanics of all interacting orbital systems, from the formation of solar systems to the evolution of galaxies. What is learned of Saturn’s atmosphere and its magnetosphere can apply to the atmosphere and the magnetosphere that keep us alive. By learning about Saturn and its environment and its retinue of moons we can better appreciate what it means to live on a planet orbiting a star.

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REFERENCES

Cassini website: http://saturn.jpl.nasa.gov
Huygens website: http://sci.esa.int/huygens

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