Galileos' Legacy to Cassini: Historical, Philosophical, and Physical

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Abstract

Galileo Galilei left a rich scientific legacy that enabled Cassini, Huygens and other scientists to continue to open the modern era of planetary exploration. The legacy relationship also applies to the spacecraft and missions named after these men. The fundamental philosophy of the Cassini/Huygens mission and its investigative approach were adopted from the Galileo mission. The Cassini spacecraft even uses spare hardware that the Galileo Project did not use. Thus the parallels between the two missions run very deep. This thesis is reinforced in the following description of the Cassini and Huygens missions. Many things are seen to resemble their counterparts on the Galileo mission at Jupiter.

1. Introduction

In this chapter we look at the present and to the promise of the future. Here we can *see* how the legacies of the *three* Galileos *will* benefit the *Cassini/Huygens* mission to Titan and the Saturnian system. With his discoveries Galileo Galilei opened the modem era of planetary exploration, His work provided some of the fundamental reasons for sending spacecraft to explore the planets. His discovery of the rings of Saturn provided one of the particular reasons to visit that planetary system. *Galileo,* the mission to Jupiter, is providing a different legacy to *Cassini/Huygens.* This is evident in *three* ways: in the philosophy underlying the organization of that mission, in the example of how it is flown, and in terms of spare hardware which will now fly on *Cassini/Huygens.* The legacy from *Galileo,* the telescope, lies in the future, but it will happen before *Cassini/Huygens* reaches Saturn. It will be in the nature of new information about Saturn and its system which will be used to help *Cassini/Huygens* to achieve the many objectives of its mission.

Cassini/Huygens is going to Saturn because of the rich opportunities for exploration and discovery. Saturn is the second most massive planet in the Solar System. It has the most phenomenologically rich system of rings. The planet-sized satellite Titan has a dense, veiling atmosphere. Some seventeen icy satellites are known. The magnetosphere is large, extensive, and maintains a dynamic interface with the solar wind. There are many places in this system where *Cassini/Huygens* needs to carry its instruments so that they can make *in situ* measurements, or observe targets under specific geometrical circumstances such as range and angles of illumination and emission.

The Cassini/Huygens mission is designed to carry out an in-depth exploration of the Saturnian system. The spacecraft starts its interplanetary journey on October 1997 aboard a Titan-IVB-Centaur launch vehicle. Upon arrival at Saturn, Cassini will go into orbit about the planet. The Cassini spacecraft carries a smaller spacecraft, the Huygens Probe, which goes to Titan, Saturn's largest moon. The orbiter delivers the Huygens probe to Titan in November 2004. After deceleration in Titan's upper atmosphere, Huygens deploys a parachute system and its six instruments make scientific measurements and observations during the descent to the surface. These data are then transmitted to the orbiter which, in turn, relays them to the Earth, The orbiter will then commence a four-year tour of the Satumian system. With its complement of twelve instruments, Cassini is capable of making a wide range of in situ and remote-sensing observations. There are repeated close flybys of Titan both to make measurements and to obtain observations. The Titan flybys also provide gravity-assisted orbit changes, which enable Cassini to visit other satellites, and various parts of the magnetosphere, and to obtain occultations of the rings and atmospheres of Saturn and Titan. Over the span of the mission, Cassini is expected to record temporal changes in many of the properties that it can observe.

The primary goal of Cassini/Huygens is to "conduct an in-depth . . . exploration of the Saturnian System (NASA, 1989). The mission is a joint undertaking by NASA and ESA. The *Huygens* probe is supplied by ESA while the Saturn Orbiter is provided by NASA. The scientific payloads on both the Orbiter and the Probe are provided by scientific groups supported by NASA and by the national funding agencies of the member states of ESA. The Italian Space Agency contributes to several instruments on both the Probe and the Orbiter and it also provides, through a bilateral agreement with NASA, part of the Orbiter telecommunication subsystem, inducting the high-gain antenna. The launch vehicle is provided by NASA. NASA is also to provide the launch, mission operations, and telecommunications via the Deep Space Network (DSN). *Huygens* operations are carried out by ESA. Late in 1990, NASA and ESA simultaneously selected the payloads respectively for the Saturn Orbiter and for the *Huygens* Probe. Both agencies also selected interdisciplinary invest igations. The ESA *Huygens* selection comprises six principal investigator (PI) instruments and three interdisciplinary scientist (IDS) investigations. The NASA Saturn Orbiter selection comprises seven PI-instruments, five facility instruments, and seven IDS investigations.

The overall mission is named after the French/Italian astronomer Jean-Dominique Cassini, who discovered several Saturnian satellites and rings features (the Cassini division) in the period 1671-1685. The ESA probe is named *Huygens* after the Dutch astronomer Christian Huygens who discovered Titan in 1655.

In the next section we discuss the legacies from the three Galileos -Galileo Galilei, the *Galileo* Project, and the *Galileo* telescope. The overview of the *Cassini/Huygens* mission begins with a description of the spacecraft and the scientific instruments. Then the route leading to Saturn is traced across the solar system. *Huygens*' mission to Titan is summarized and we briefly look at the *Cassini* orbital tour at Saturn. The scientific objectives for *Cassini/Huygens are* reviewed and then we go to the launch pad for the launch on October 6, 1997 !

2. Legacies from Three Galileos

In 1610 Galileo Galilei , observing from Padova, Italy, produced the first drawing documenting his discovery of Saturn's rings (Figure 1). He was puzzled by what he saw. By 1616, however, he had better telescope optics and produced the drawing in Figure 2. Nine years later Jean-Dominique Cassini was born in Perinaldo, Republic of Genoa. Another forty-five years passed until Cassini produced a drawing of Saturn that indicated his discovery of a major gap in the rings, one which bears his name (Figure 3). Cassini also discovered the satellites Iapetus, Rhea, Tethys, and Dione.

The many similarities between the *Galileo* mission and the *Cassini/Huygens* mission is a testimonial to the profound effect the example of the *Galileo* mission has had on the conception, planning and development of the *Cassini/Huygens* mission. The techniques of getting to Saturn, the philosophy of instrument complement, the Probe design, the orbital tour design, and the instrument designs and hardware are areas where the underlying ideas were adopted from *Galileo.* The profound influence of the *Galileo* legacy will become more and more apparent as we describe the *Cassini/Huygens* mission.

The instrumental philosophy of *Cassini/Huygens was* adopted from that of the *Galileo* Project. By in large, the same rationale applied and similar instrument types were necessary in order to achieve the broad scientific objectives set for the Saturnian mission. *Cassini/Huygens will* record the present state of Titan and of the Saturnian system. It will try to identify and study the ongoing processes in the system. Care will be taken to learn how the system has evolved (i.e., its "history") so the present state can be projected backward in time. From all of this information, and from constraints learnt elsewhere, the origin (i.e., the "prehistory") of the system will be inferred. As with *Galileo,* on *Cassini/Huygens* the choice of instruments reflects the fact that the breadth of the scientific survey is of paramount importance. Beyond the ability to make planned observations and measurements and a strategy which seeks to explore and search for new discoveries, is the ability to follow up new discoveries with appropriate measurements and observations. One can draw an analogy between the workings of the Saturnian system and a clock. A mere listing of the properties of the components does not describe the device. The essence of a clock is the interaction among the components. Not only is this a legacy from the *Galileo* Project, but it is a philosophy which Galileo Galilei himself could easily have endorsed.

Another way that the *Galileo* Project is contributing to *Cassini* is through actual pieces of hardware. These were spares built for *Galileo* but were not used, Fortunately they were available for Cassini. These include one of the radioisotope thermal generators (RTG) and some of the radioisotope heater units (RHU). The Near-Infared Mapping Spectrometer (NIMS) engineering model became the starting point for the flight model of infrared part of Cassini's VIMS (Visual and Infrared Mapping Spectrometer), Some of the software aboard the *Cassini* spacecraft was imported and or adapted from that developed for *Galileo.*

As previously indicated, the impact of *Galileo*, the telescope, will depend upon future developments. Given the superb imaging quality of this telescope, it is likely to yield many observations of Saturn. The results from these data will influence the choices made by the *Cassini* science teams in choosing how to operate their instruments and which measurements or observations to make and, perhaps, when to make them. In this regard there are two obvious considerations that apply. First, *Cassini/Huygens* can only be in one place at a time. With a number of time variable and spatially variable phenomena to study, ground-based observations can provide a context for the separation of temporal and spat ial effects. Secondly, the capabilities of the *Cassini Huygens* instruments became fixed several years ago as their designs were frozen. Some state of the art capabilities could not be included at that time due to constraints such as schedule. Since then, instrument technology has continued to evolve. New capabilities are being created all of the time. Thus, in the year 2004, it will be possible to make types of observations from the Earth (or Earth orbit) which cannot be made by *Cassini/Huygens*.

3. The Cassini Spacecraft

At the time of launch, the mass of the fully fuelled spacecraft will be about 5630 kg. As shown in Color Figure 1, *Cassini* consists of several sections. Starting at the bottom of the "stack" and moving upward, these are the lower module, the propellant tanks together with the engines, the upper equipment module, the twelve-bay electronics compartment, and the high-gain antenna. These are all stacked vertically on top of each other. Attached to the side of the stack (away from the viewer) is an approximately three-meter diameter, disk-shaped spacecraft the *Huygens Titan Probe*. Most of the scientific instruments are installed on one of two body-fixed platforms. These are called the remote-sensing pallet and the particles-and-fields pallet and are named after the type of instruments they support. The big 8-meter-long boom supports sensors for the magnetometer experiment. Three skinny ten-meter-long electrical antennae point in orthogonal directions. These are sensors for the Radio and Plasma Wave Science (RPWS) experiment. At the top of the stack is the large, 4-meter diameter high-gain antenna. Centered and at the very top is a relatively small low-gain antenna. Another low-gain antenna is located near the bottom of the spacecraft.

Two-way communication with *Cassini will be* through the Deep Space Network (DSN) via an X-band radio link which uses either the 4-meter-diameter high-gain antenna (HGA) or one of the low gain antennae. The high-gain antenna is also used for radio and radar experiments and for receiving signals from *Huygens*. *The* electrical power for the spacecraft is supplied by three radioisotope thermoelectric generators. *Cassini is* a three-axis-stabilized spacecraft. The attitude of the spacecraft is changed by using either reaction wheels or the set of 0.5 N thrusters. Attitude changes will be done frequently because the instruments are body-fixed and the whole spacecraft must be turned in order to point them. Consequently, most of the observations will be made without a real-time communications link to the Earth. The data will be recorded on two solid-state recorders, each having a storage capacity of about two gigabits. Because of this communications constraint, the scientific data will be obtained primarily by using one or the other of two modes of operation. These modes have been named after the functions being carried out, namely, the *remote-sensing mode,* and the *fields-and-part icles-and-downlink mode*. During remote-sensing operations the recorders are filled with images and spectroscopic and other data which are obtained as the spacecraft points to various targets. During the fields-and-particles-and-downlink mode the high-gain antenna is pointed at the Earth and the stored data is transmitted to the DSN. Also, while in this mode, the spacecraft is slowly rolled about the axis of the high-gain antenna. This allows the sensors on the fields-and-particles pallet to scan the sky and determine directional components for the various quantities that they measure.

Cassini/Huygens accommodates some twenty-seven different scientific investigations which are supported by eighteen specially designed instruments, twelve on the Orbiter and six on the *Huygens* probe.

4. The Huygens Probe

The *Huygens* Probe itself is the spacecraft that is destined for entry into Titan's atmosphere. It carries a capable, diverse, set of instruments for measuring atmospheric and surface properties.. However, the *Huygens* Probe System also has another part, the Probe Support Equipment, which is permanently attached to the *Cassini* Orbiter. Here is located the spin-eject device. At the right time, it triggers the release of a strong spring-loaded mechanism which simultaneously propels the Probe away from the Orbiter (with a relative velocity of 0.3 to 0.4 m/s) and imparts to it a spin about its axis of more than 5 rpm. Altogether, the Probe weighs about 305 kg and the Probe Support Equipment weighs about 35 kg.

The *Huygens* probe is a very bluntly shaped conical capsule with a high drag coefficient. It consists ofa descent module that is enclosed by a thermal-protection shell. The front shield of this shell is 2.7 meters in diameter. It is covered with a special thermal ablation material to protect the Probe from the enormous flux of heat generated during atmospheric entry. On the aft side is a protective cover that is primarily designed to reflect away the heat radiated from the hot wake of the Probe as it decelerates in Titan's atmosphere,

After the Probe has separated from the Orbiter, electrical power is provided by five lithium sulfur dioxide batteries. They have a total energy capacity of about 1800 Wh. The Probe carries two S-band transmitters and antennae, both of which are transmitting to the Orbiter during the Probe's descent. One stream of telemetry is delayed by about six seconds with respect to the other to avoid data loss if there are brief transmission outages.

5. The Cassini/Huygens Mission

The *Cassini/Huygens* mission is designed to explore the Saturnian system and all its elements, *i.e., the* planet Saturn and its atmosphere, its rings, its magnetosphere, Titan and many of its icy satellites. The mission will pay special attention to Titan, Saturn's hugest moon. *Cassini will* make repeated close flybys of Titan both for gathering data about Titan and for gravity-assisted orbit changes. These maneuvers will permit the rotation of the orbit around the Sun-Saturn line and the achievement ofa wide range of orbit inclinations. In turn this will enable a tour of the satellites with several close flybys, reconnaissance of the magnetosphere over a wide range of locations, the observation of the rings at various illumination and occultation geometries, and observation of Saturn at various phase angles.

5.1. 1NTERPLANETAR% TRAJECTORY

The spacecraft will be injected into a 6.7-year Venus-Venus-Earth-Jupiter Gravity Assist (VVEJGA) trajectory to Saturn. The interplanetary trajectory is illustrated in Figure 4 on which several key dates are shown. Included are gravity assists from Venus (April 1998 and June 1999), Earth (August 1999) and Jupiter (December 2000). Arrival at Saturn is planned for 1 July 2004. During most of the early portion of the cruise, communication with the spacecraft will be via one or the other of the low-gain antennae (LGAs). Six months after the Earth flyby, the spacecraft will turn to point at Earth and then subsequent communications will be via the HGA. Following the Jupiter flyby, the spacecraft will be used in an attempt to detect gravitational waves using its Ka-band and X-band radio equipment. Instrument calibrations will also be done during the cruise between Jupiter and Saturn, Science observations will begin two years away from Saturn (about 1.5 years after the Jupiter flyby).

The most critical phase of the mission after launch is the Saturn Orbit Insertion (S01) phase, which will take place in June 2004. Not only will it be a crucial maneuver, but it will also be a period of unique science activity since at that time the spacecraft will be the closest it will ever be to the planet. The SOI part of the trajectory will provide a unique observation geometry for the rings

5.2. HUYGENS TITAN PROBE MISSION

Huygens' encounter with Titan is planned on November 11,2004. *Huygens* will be released from the orbiter 21 to 22 days before the first Titan flyby, as shown in Figure 5. Two days after probe release, the Orbiter will perform a deflection maneuver. This keeps the Orbiter from following *Huygens* into Titan's atmosphere. It also sets up the required radio communication geometry between the Probe and the Orbiter which is needed during the Probe descent phase. This maneuver will also set the initial conditions for the satellite tour, which starts right after the completion of the Probe mission,

Once the Probe has decelerated to about Mach 1.5, the aft cover is pulled off by a pilot parachute. An 8.3-m in diameter main parachute is then deployed to ensure a slow and stable descent, The main parachute slows the Probe, and allows the decelerator and heat shield to fall away when it is released. To limit the duration of the descent to a maximum of 2.5 hours, the main parachute is jettisoned at entry +900 seconds and replaced by a smaller, 3. O-m diameter, drogue chute for the remainder of the descent. The entry and descent sequence is illustrated in Color Figure 2 which shows the major events. The batteries and all other resources are sized for a maximum mission duration of 153 minutes, corresponding to a maximum descent time of 2.5 hours and with at least 3 minutes, but possibly half an hour or more, on the surface. The instrument operations are commanded either on the basis of time (in the top part of the descent) or on the basis of measured altitude (in the bottom part). The altitude will be measured by a small radar altimeter during the last 10-20 km of the descent.

Throughout the descent, HAS1 will measure more than a half dozen physical properties of the atmosphere. It will also process signals from the probe's radar altimeter in order to gain information about surface properties. The Gas Chromatograph and Mass Spectrometer (GCMS) will determine the chemical composition of the atmosphere as a function of altitude. The Aerosol Collector and Pyrolyzer (ACP) will capture aerosol particles, pyrolyze them, and send the effused gas to the GCMS for analysis. The optical radiation propagation in the atmosphere will be measured intensively by the Descent Imager and Spectral Radiometer (DISR). This instrument will also image the cloud formations and the surface. As the surface is neared, the DISR will switch on an i l Rumination lamp and measure the spectral reflectance of the surface. Throughout its descent the doppler shift of *Huygens'* telemetric signal will be measured by the Doppler Wind Experiment (DWE) equipment on the orbiter in order to determine the atmospheric winds, gusts, and turbulence. In the proximity of the surface the Surface Science Package (SSP) will activate a number of its devices to make measurements near and on the surface. If touchdown occurs in a liquid, such as in a lake or a sea, SSP will measure the liquid's physical properties.

5.3. A SAMPLE CASSINI ORBITAL TOUR

After the end of the probe mission, the Saturn Orbiter will start its four-year tour. This tour consists of more than forty Saturn-centered orbits, connected by Titan gravity-assist flybys or propulsive maneuvers. 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: Titan ground-track coverage, flybys of icy satellites, Saturn, Titan, or ring occultations, orbit inclinations, and ring-plane crossings. Titan is the only Saturnian satellite that is large enough to enable significant gravity-assisted orbit changes. The smaller icy satellites can help sometimes with their small perturbations which can be useful in trimming a trajectory. The design of the *Cassini* orbital tour is a complicated and challenging task that is currently under study. Work on it will not be complete for at least several years. Nevertheless, one of the studied tours (Tl 8-1) can be used to illustrate the complexity involved in this type of navigational planning. It is illustrated in Color Figure 3.

T1 8-1 has 42 Titan flybys. There are six targeted flybys of icy satellites. These are tabulated in Table 3. Here, "targeted" means that the flyby distance can be chosen to be the value that is best for the observations to be made. The table also shows the closest approaches made by *Voyager*.

In addition to the targeted flybys, there are serendipitous flybys that occur as a matter of chance in any tour. In T 18-1 there are 39 of these with flyby distances of less than 100,000 km. They are listed in Table 4. At a range of 100,000 km the pixel resolution of Cassini's narrow-angle camera is about 0.6 km. This resolution is substantially better than those achieved by *Voyager* for most of the icy satellites.

6. Scientific Objectives

The scientific objectives for *Cassini/Huygens* can be organized by mission phase and by target. The planet, the rings, the magnetosphere, and the icy satellites all have a set of objectives. Titan has objectives for the Orbiter and the Probe. It also has objectives which address the synergistic acquisition of data by both spacecraft. All the objectives arose from the work of a Joint Science Working Group convened by ESA and NASA to study the possibilities for a Saturn orbiter mission. The results of this study are documented in the group's final report (ESA, 1989a). The objectives then became formalized with their inclusion in the NASA and ESA announcements of opportunity (ESA, 1989b; NASA, 1989, 1991).

6.1. SCIENTIFIC OBJECTIVES BEFORE REACHING SATURN

Given the trajectory for the long voyage to Saturn, *Cassini/Huygens* has the opportunity to carry out a number of experiments during this cruise phase. After launch there will be instrument checkouts and maintenance activities. Gravitational wave searches will be carried out during the three successive oppositions of the spacecraft, beginning in December 2001. These are radio experiments that involve two-way Ka-band Deep Space Network (DSN) tracking of the spacecraft. During two solar conjunctions of the spacecraft, a series of radio propagation measurements obtained from two-way X-band

and Ka-band DSN tracking will provide a test of general relativity, as well as data on the solar corona,

In early 1992, the (*'assini* project team at the Jet Propulsion Laboratory redesigned the mission and the Saturn Orbiter to meet NASA budgetary constraints expected for the following years. As a result of this re-structuring, most of the scientific objectives for targets of opportunity (asteroid flyby, Jupiter flyby, and cruise science (NASA, 1989, 1991; Lebreton, 1991)) have been deleted. This was part of the effort to control development costs and the cost of operation during the first few years in flight. In the current baseline plan the scientific data acquisition would start 2 years before arrival at Saturn; i.e., well after the Jupiter flyby.

6.2. TITAN

Both the *Huygens* Probe and the *Cassini* Orbiter will study Titan. Their scientific objectives are to:

- *Determine abundances of atmospheric constituents (including any noble gases; establish isotope ratios for abundant **elements; constrain scenarios of formation and evolution of 7'itan 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 photochemistry of the stratosphere; study connation and composition of aerosols;***
- ***Measure winds and global temperatures; investigate cloud physics, genera! 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***

In the design of the *Huygens* measurements and Orbiter observations it is highly desirable that the value of the whole set of data be maximized. To strive for this synergistic effect, there are some specific objectives that have been identified (ESA, 1989b):

- ***Each*** time ***the Orbiter will fly by Titan, it will perform a set of atmosphere and surface remote-sensing observations which will include re-observations of the atmosphere and surface along the flight path of the Probe***
- ***In this respect the Probe data will provide a reference set of data which will be used to "calibrate" the Orbiter observations. 1 'he Probe data will be used, together with the Orbiter data, for studying spatial and seasonal variations of the atmosphere composition and dynamics***

6.3. MAGNETOSPHERE

Specific *Cassini* objectives for magnetosphere science are to:

- ***Determine the configuration of the nearly axially symmetric magnetic-field and its relation to the modulation of Saturn Kilometric Radiation (SKR).***
- ***Determine current systems, composition, sources, and sinks of magnetosphere charged particles.***
- ***Investigate wave-particle interactions and dynamics of the dayside magnetosphere and the magnetotail of Saturn and their interactions with the solar wind, the satellites, and the rings.***
- ***Study the effect of Titan's interaction with the solar wind and magnetospheric plasma.***

- *Investigate interactions of Titan's atmosphere and exosphere with the surrounding plasma.*

6.4. SATURN

Specific *Cassini* objectives for the planet Saturn are to:

- *Determine temperature field, cloud properties, and composition of the atmosphere of Saturn.*
- *Measure the global wind field, including wave and eddy components; observe synoptic cloud features and processes.*
- *Infer the internal structure and rotation of the deep atmosphere.*
- *Study the diurnal variations and magnetic control of the ionosphere of Saturn.*
- *Provide observational constraints ("as composition, isotope ratios, heat flux, etc.) on scenarios for the formation and the evolution of Saturn.*
- *Investigate the sources and the morphology of Saturn lightning (Saturn Electrostatic Discharges (SED), lightning whistlers).*

6.5. SATURN'S RING SYSTEM

Specific *Cassini* objectives for ring science are to:

- *Study configuration of the rings and dynamical processes (gravitational, viscous, erosional, and electromagnetic) responsible for ring structure.*
- *Map composition and size distribution of ring material.*
- *Investigate interrelation of rings and satellites, including imbedded satellites.*
- *Determine dust and meteoroid distribution in the vicinity of the rings.*
- *Study interaction between the rings and Saturn's magnetosphere, ionosphere, and atmosphere.*

6.6. ICY SATELLITES

Specific *Cassini* objectives for icy satellite science are to:

- *Determine the general characteristics and geological histories of the satellites.*
- *Define the mechanisms of crustal and surface modifications, both external and internal.*
- *Investigate the compositions and distributions of surface materials, particularly dark, organic rich materials and low melting point condensed volatiles.*
- *Constrain models of the satellites' bulk compositions and internal structures.*
- *Investigate interactions with the magnetosphere and ring systems and possible gas injections into the magnetosphere.*

7. Launch

The launch vehicle for *Cassini/Huygens* is a *Titan IVB* with two *Solid Rocket Motor Upgrades* (SRMU) and with a *Centaur* rocket for the upper stage. This system puts *Cassini/Huygens* into Earth orbit and then, at the right time injects it upon its interplanetary trajectory. The "core" Titan vehicle has two stages. The SRMUs are anchored to the first, or lower, stage. These "strap-on" rockets burn solid fuel, whereas the Titan uses liquid-fuel. The Centaur is a versatile, high-energy, cryogenic-liquid-fueled upper stage with two multiple-start engines. The performance of the Titan IVB-SRMU-Centaur system is capable of placing a 5760-kg payload in a geostationary orbit. On top of all this propulsive might sits *Cassini/Huygens*, protected by a 20-meter-long payload fairing.

Liftoff is from Cape Canaveral Air Station, launch complex 40. It is early in the morning of October 6, 1997. The launch sequence begins with the ignition of the two SRMUs. They lift the stack off of the pad. About ten seconds after liftoff, the stack continues to accelerate, and now, it starts to tilt and rotate. The rotation continues until the required azimuth is reached. At plus two minutes the first stage of the Titan is ignited. The altitude is approximately 192,000 feet. A few seconds later the two, now spent, SRMUs are jettisoned. One-and-a-half minutes pass. At an altitude of 360,000 feet, the payload fairing is let go. It is about five and a half minutes into the flight when an altitude of 549,000 feet is reached. The first stage of the Titan separates at this altitude and the second stage fires. At launch plus nine minutes the second stage has burnt out and drops away. Now, it is the Centaur's turn to fire. It boosts the remaining rocket-and-spacecraft stack into a parking orbit and turns off its engines. Some sixteen minutes later the Centaur ignites for a second time. The bum lasts between 7 and 8 minutes. When it is done the Centaur separates from the spacecraft. *Cassini/Huygens* is now on an interplanetary trajectory, headed for Venus.

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Captions

Figure 1. Galileo Galilei's first drawing of Saturn (Galileo, 161 O).

Figure 2. Galileo's drawing of Saturn as observed through a higher quality telescope (Galileo, 1616).

Figure 3. Cassini's drawing of Saturn showing the gap in the rings (Cassini, 1675).

Figure 4. Interplanetary trajectory of the *Cassini/Huygens* spacecraft.

Figure 5. Arrival at Saturn. The *Cassini/Huygens* trajectory is adjusted near the apogee of the first orbit so as to target Titan. *Huygens* is released about half way from that point to Titan.

Figure 4. Cassini's orbital tour of the Saturnian system. An example of a typical four-year satellite tour. (T18-1)

Color Figure 1. The *Cassini spacecraft*

Color Figure 2. The Entry and descent scenario of the *Huygens* Titan Probe

Color Figure 3. A sample orbital tour of the Saturnian system (T1 8-l).

Table 1. The *Cassini* Orbiter instruments

Table 2. The *Huygens Probe* instruments.

Table 3: Targeted flybys of icy satellites.

Table 4. Chance flybys of icy satellites.

‘I’able 1. Cassini Orbiter Instruments

Instruments	Participating Countries	Measurements	Techniques
Optical remote-sensing instruments			
Composite Infrared spectrometer (CIRS)	U. S. A., Aust, Fr., Ger., It., U.K	High resolution infrared spectra, 10- I 400 cm”’	Spectroscopy using 3 interferometric spectrometers
Imaging, science Subsystem (ISS)	U. S. A., Fr., Ger., U.K	Photometric images through filters, 0.2-1. I mm	Imaging with CCD detectors; 1 wide angle camera (61. 2 rnr fov); 1 narrow angle camera (6. I mr fov)
Ultraviolet Imaging Spectrograph (UVIS)	U.S.A., Fr., Ger.	Spectral images. 55-190 nm, occultation photometry, 2 ms; H and D spectroscopy, 00004 nm resolution	Imaging spectroscopy, 2 spectrometers Hydrogen-Deuterium absorption cell
Visible and Infrared Mapping spectrometer (VIMS)	U.S A., Fr., Ger., 11.	Spectral images, 0.35-1 .05mm (0.073mm res), 0.85-5. I mm (O. 166mm res); occultation photometry	Imaging spectroscopy, 2 spectrometers
Radio remote-sensing instruments			
RADAR	U.S.A., Fr., It., U.K.	Ku-band RADAR images (13,777.5 MHz); Radiometry, <0.5 K resolution	Synthetic aperture radar; radiometry with a microwave receiver
Radio Science Subsystem (RSS)	U.S.A., It.	Ka, S, and X bands; frequency, phase, timing, and amplitude	X- and Ka-band transmissions to *Cassini*; Ka-, S- and X-band transmissions to the Earth
Particle remote-sensing and in situ measurement instrument			
Magnetospheric Imaging Instrument (MIMI)	U.S.A. Fr., Ger.	Image energetic neutrals and ioos <10 keV -8 MeV/nucleon; composition 10-265 keV/e ions; charge state, composition; directional flux 20 keV-130 MeV ions; 15keV to >1 MeV electrons; directional flux	Particle detection and imaging Ion-neutral camera (time of flight, total energy detector) Charge-energy-mass spectrometer Solid state detectors with 1) magnetic focusing telescope, and 2) aperture controlled -45° field of view
In situ measurement instruments			
Cassini Plasma Spectrometer (CAPS)	U.S.A., Fin, Fr., Hun, Nor. U.K	Particle energy/charge 0.7-30,002 eV/e 1-50,000 eV/e 1-50,000 eV/e	Particle detection and spectroscopy. Electron spectrometer; Ion mass spectrometer; Ion beam spectrometer
Cosmic Dust Analyzer (CDA)	Ger., Cz., Fr., Nor., U.K, U.S A, ESA	Directional flux and mass of dust particles in range of 10^{-16} to 10^{-6} g	Impact induced currents
Dual Technique Magnetometer (MAG)	UK, Ger., It., U.S.A.	B DC to 4 Hz up to 2 56 nT. Scalar field DC to 20 Hz up to 44000 nT	Magnetic field measurement Flux gate magnetometer, Vector/scalar magnetometer
Ion and Neutral Mass Spectrometer (INMS)	U.S A, Ger.	Fluxes of +ions and neutrals in mass range of 1-66 amu	Mass spectrometry
Radio and Plasma Wave Science (RPWS)	U. S A., Aust, Fr, Swed, U.K, ESA	E 10 Hz - 2 MHz B 1 Hz - 20 kHz Plasma density	Radio frequency receivers 3 electric dipole antennas; 3 magnetic search coils; Langmuir probe current

Table 2. Huygens Instruments

Instruments	Participating Countries	Measurements	Techniques
Huygens Atmospheric Structure Instrument (HAS])	It., Aust, Ger., Fin., Fr., Nor., Sp., U.S. A., U. K., ESA	Temperature: 50-300K. Pressure: 0-2000 mbar. Gravity: 1 μg-20 mg AC E-field: O-10 kHz,80dB at 2 ~VnfHz45 DC E-field: 50dB at 40 mV/m Electrical conductivity: 10^{-15} Ω/m to ∞ Relative permittivity: 1 to ∞ Acoustic: O-5 kHz, 90dB at 5mPa	Direct measurements using "laboratory" methods.
Gas Chromatography and Mass Spectrometer (GCMS)	U. S. A., Aust , Fr.,	Mass range: 2-146 amu Dynamic range: > 10* Sensitivity: 10"[12] mixing ratio Mass resolution: 10^{-6} at 60 amu	Chromatography and mass spectrometry: 3 parallel chromatographic columns; quadrapole mass filter; 5 electron impact sources
Aerosol Collector and Pyrolyzer (ACP)	Fr., AuSt., U.S.A.	2 samples: 150-45 km, 30-15 km altitude	3 step pyrolysis: 20°C, 250"C, 650°C
Descent Imager and Spectral Radiometer (DISR)	U. S. A., Ger., Fr.	Upward and downward spectra: 480-960nm, 0.87-1.7μm, resolution 2.4-6.3 run; downward and side-looking images: 0.66-1 μm; solar aureole photometry, 550nm, 939nm; surface spectral reflectance	Spectrophotometry, imaging, photometry, and surface illumination by lamp.
Doppler Wind Experiment (DWE)	Ger., It., U.S.A.	(Allan Variance) .10 (m 1 S),5x10 (in 10s), 10^{-12} (in 100s), cm-responding to wind velocities of 2 m/s to 200 m/s, probe spin	Doppler shift of *Huygens* telemetry signal, signal attenuation
Surface Science Package (SSP)	U. K., It., U. S. A., ESA	Gravity: 0-100 g. Tilt: ±60°. Temperature: 65-100 K. Thermal conductivity: 0-400 mW $m^{-1}K^{-1}$. Speed of sound: 150-2000 m/s. Liquid density: 400-700 kg m^{-3}. Refractive index: 1.25-1.45	Impact acceleration; acoustic sounding, liquid relative permittivity, density and index of refraction

Table 3. Targeted Flybys of Icy Satellites*

Number of Flybys	Satellite	*Voyager* Closest Approach (km)
1	Iaepetus	909,000
2	Enceladus	87,000
2	Dione	162,000
1	Rhea	74,000

* The actual flyby can be as close as desired, Tour T 18-1.

flyby ↘

Table 4. Range Distribution for Chance Flyby s* compared to Voyager

Satellite	Closer than 10,000 km	10,000 - 50,000 km	50,000- 100,000 km	Best *Voyager* f range (km)
Mimas	1	2	1	88,000
Enceladus		3	4	87,000
Tethys	1	2	4	93,000
Dione		1	2	161,000
Rhea			2	74,000
Phoebe (On Saturn approach)		1		2,076,000

"For flybys with closest approach on the sunlit side. Tour T18-1.