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Cassini Program Update

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CASSINI PROGRAM UPDATE

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Abstract

The Cassini Project is NASA's next mission to the outer planets. Managed at the Jet Propulsion Laboratory and with the joint participation of the European Space Agency (ESA) and Agenzia Spaziale Italiana (ASI), Cassini will accomplish a comprehensive survey of the planet Saturn, Titan and the icy satellites of the Saturnian system, the rings, and the Saturnian magnetosphere. Early in 1992, the Project experienced significant change as the realities of the national economy and budget pressures forced a NASA-wide review of its programs. The Comet Rendezvous/Asteroid Flyby (CRAF) mission was deleted from the CRAF/Cassini Project and the remaining Cassini project was further rescope to reduce cost. Many of the cost-savings measures involved reducing the capabilities of the spacecraft system. This paper examines the features of the redesigned spacecraft at the time of the rescope in Spring, 1992 and compares it to today's design 18 months later.

Cassini Mission Overview

In October 1997, the Cassini spacecraft will be launched using a Titan IV/Centaur launch vehicle. The spacecraft will be placed on a 6.7-year Venus-Venus-Earth-Jupiter Gravity Assist (VVEJGA) Trajectory to Saturn (Fig. 1). The Venus gravity assists enable a much greater injected mass, providing for more science opportunities at Saturn. The perihelion of the first orbit is 0.68 AU* and is the spacecraft's closest approach to the Sun. Communications during the inner solar system cruise, including the Venus leg, is limited to the use of one of the spacecraft's low-gain antennas, since the high-gain antenna is needed to shade most of the spacecraft.

The Earth flyby in August 1999 places the Cassini spacecraft on a trajectory for a Jupiter encounter 16 months later. During the cruise between Jupiter and Saturn, the science instruments are turned on and calibrated. In June 2004, the spacecraft arrives at Saturn. The closest approach to Saturn (an altitude of 0.3 Saturn radii) occurs during the 88-minute Saturn Orbit Insertion (SOI) maneuver. Due to this unique science opportunity (ring occultations, high-resolution imaging, etc.), the start of the maneuver is delayed until periapsis so that science observations can be made during approach.

*An astronomical unit (AU) is the mean distance between the Sun and the Earth, about 150 million km.

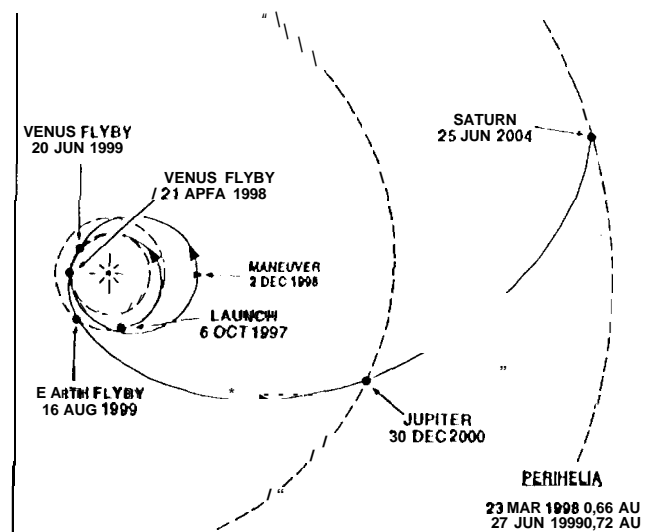


Fig. 1. Cassini Oct. 1997 VVEJGA Interplanetary Trajectory

Halfway through the orbiter's initial 152-day orbit the main engine is fired again to raise periapsis and to establish the proper geometry for the Huygens Probe release and relay. Probe release occurs about 22 days prior to the first Titan flyby. The Probe flies directly into Titan's atmosphere. During descent it gathers *in situ* data of the atmosphere constituents and winds, telemetering them back to the spacecraft for storage and later replay back to Earth. The Probe mission lasts up to 2.5 hours before the Probe impacts the surface.

The orbiter's mission lasts for four years during which there are multiple Titan encounters for both science acquisition and gravity-assisted orbit modification. Numerous Sun and Earth occultations are planned for Saturn and Titan, as are flybys of selected icy satellites. Toward the end of the four-year tour, the orbits will have become oriented such that the apoapses will be aligned in a nearly anti-Sun direction and the inclination will approach 85 degrees. This geometry will permit magnetic tail studies and nearly vertical viewing of the rings. The baseline mission ends in June 2008, about 10.7 years after launch.

Rescoping the Cassini Project

By January 1992, the CRAF/Cassini Project had already held the Spacecraft System Preliminary Design Review (PDR) and the Attitude and Articulation Control Subsystem

- significantly reduced Project cost
- had a target dry mass of 2 100 kg (later updated to 2150 kg)
- was operationally simpler
- supported the Huygens Titan Probe and present instrument complement
- retained the foreign partnerships
- retained use of all assemblies presently on-contract.

The team was given several degrees of freedom to accomplish this task:

- the "mission mode" (real-time science acquisition vs. "Magellan Mode" (i.e., record/playback))
- the orbital tour design
- the number/extent of articulated elements, if pointing could be achieved through other means
- the number/data rate of telemetry links
- the science instrument capabilities.

On this last matter of instrument capabilities, the science representatives to the team established a lower limit of "ten times Voyager" (in terms of Saturn mission return) as an acceptance Criterion for proposed instrument changes.

Configuration/Mechanical Systems (January 1992)

The January 1992 Cassini configuration is shown in Fig. 2. The spacecraft appendages supporting the instrument platform and turntable (see below) are in their deployed, or cruise, configuration. This figure reflects the design presented at the Mission and Spacecraft System Preliminary Design Review (PDR), held June 18-21, 1991. Another view of the system is shown in Fig. 3. For scaling reference, the High-Gain Antenna (HGA) is 4 meters in diameter.

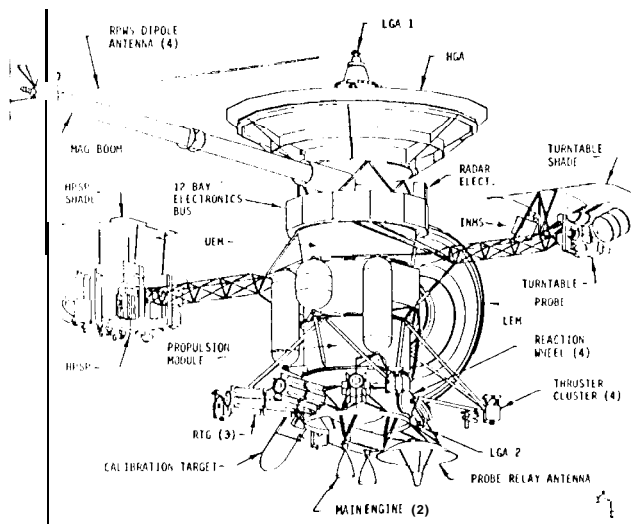


Fig. 2. Cassini Spacecraft in Cruise Configuration
January (1992)

General Description

The spacecraft was designed as a three-axis attitude-stabilized system, utilizing reaction wheels and hydrazine-fueled attitude control thrusters to provide control torques about all axes.

The spacecraft configuration included a two-axis articulated High-Precision Scan Platform (HPSi) to which were mounted instruments requiring frequent high-precision pointing and high-rate (up to 1 degree/second) slewing. A Turntable ("T1") provided a swept field-of-view (FOV) 0.1 greater than 2π steradians for fields and particles instruments. Instruments that did not require changes to their look direction were mounted on the spacecraft structure. The Cassini structure consisted of the following key elements:

Electronics Bus. The spacecraft structure incorporated a 12-bay Voyager/Galileo type electronics bus. The bus was considered a primary structural element of the spacecraft and supported the high-gain antenna and an 11-meter deployable magnetometer boom (MAG). On this boom were located the MAG sensors and the radio and plasma wave science subsystem (RPWS) antennas.

Upper Equipment Module (UEM). The UEM connected the bus to the Propulsion Module Subsystem (PMS). The UEM provided support for both the 'T1'S1' and the TT booms. An articulated redundant reaction wheel was also located on the UEM.

Lower Equipment Module (LEM). The LEM supported the three Radioisotope Thermoelectric Generators (RTGs), the three fixed AACSR Reaction Wheel Assemblies (RWA), Low-Gain Antenna 2 (LGA 2), and the spacecraft separation hardware. The LEM provided the interface to the linear separation band mounted to the launch vehicle adapter.

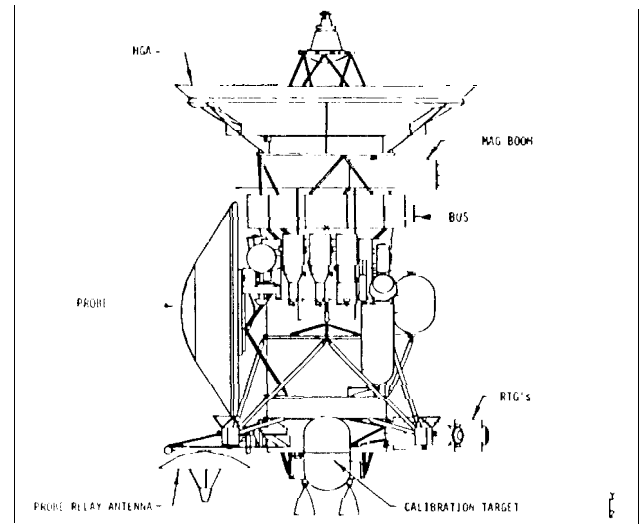


Fig. 3. Cassini Spacecraft Viewed from + Y
January (1992)

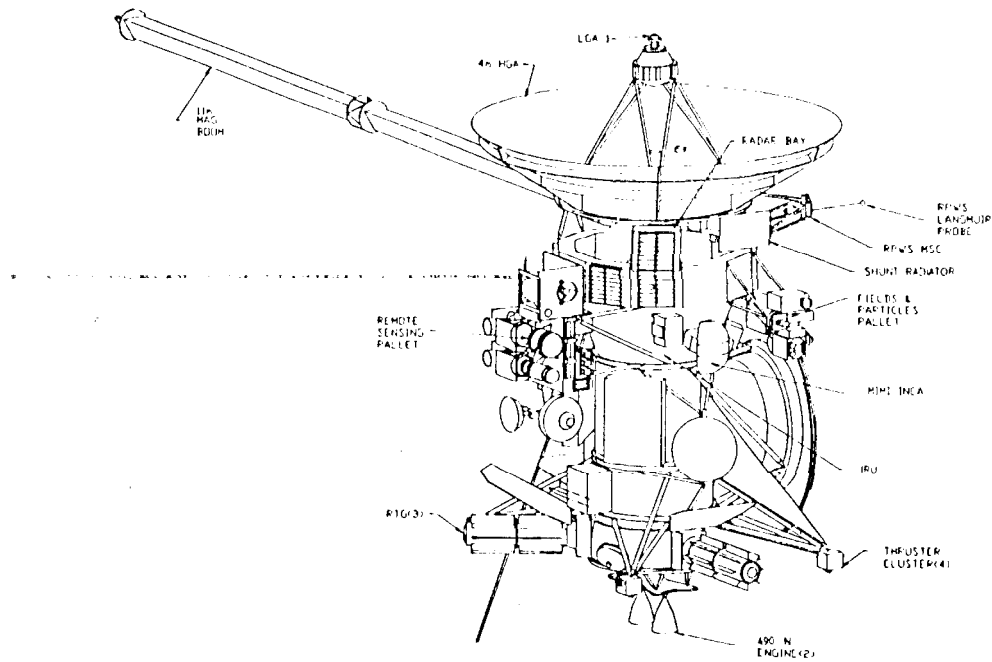


Fig. 6. Rescoped Cassini Spacecraft

to the basebody, the calibration target for the HPSP instruments is no longer useful and has been removed. Science instruments are located on two pallet structures: the Remote Sensing Pallet (RSP) and the Fields and Particles Pallet (F&P). These configurations are shown in Figs. 7 and 8, respectively.

Since the rescope of April 1992, the most significant configuration change has been the elimination of the Probe Relay Antenna (PRA). This simplification, incorporated into Figs. 6 and 7, saved mass and relaxed configuration constraints below the UEM. The Probe relay is now accomplished using the HGA.

Power Subsystem (January 1992)

The Cassini spacecraft Power and Pyrotechnic Subsystem (P&PS) has high heritage from Galileo and Voyager. The January 1992 baseline P&PS included:

- 1) a Discharge Controller Assembly (DCA) to provide transient power for clearing load faults,
- 2) a Power Control Assembly (PCA) to house the main fault-protection circuitry, general-purpose power supply (GPPS), power margin detector (PMD), and command and telemetry paths,

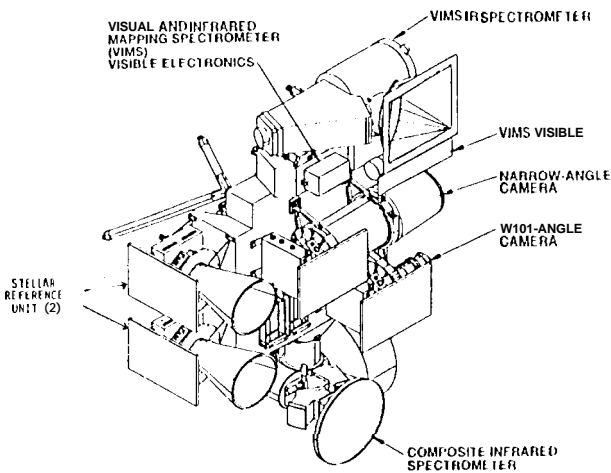


Fig. 7. Cassini Spacecraft Remote Sensing Pallet

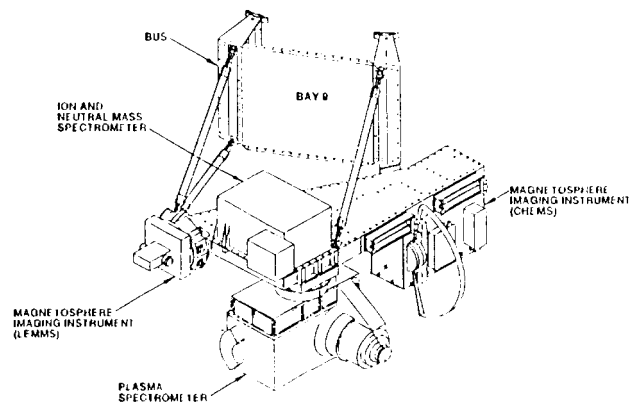


Fig. 8. Cassini Spacecraft Fields and Particles Pallet

To save costs, two of the new RTGs of the January 1992 baseline were replaced with inherited hardware. (One of them was a fueled spare generator from the Galileo project; the other was a spare converter from Galileo supplied with new fuel. For the purpose of projecting power consumption and making design decisions that effect power margin, this is the 3×10^3 W configuration that is assumed. Since then, however, the already fueled Galileo spare has been designated as the Cassini spare and replaced for flight by a new unit. The actual flight complement therefore is two new 3×10^3 Ws and a Galileo spare with new fuel. Available power estimates based on the conservatively rated RTG complement are shown below.

Mission Time	Power (Watts, 3 RTGs)
Beginning of Mission	813
Saturn Orbit Insertion	677
Probe Release	673
End of Mission	638

Telecommunications (January 1992)

The Cassini telecommunications subsystems consist of the hardware elements that provide the capability to transmit engineering and scientific data from the spacecraft as well as receive commands from the ground stations over the course of the mission. Uplink rates range from 7.8 to 500 bits/sec. Downlink data rates range from as low as 10 bits/sec used during the inner solar system cruise to rates as high as 249 kilobits/sec available during much of cruise and for brief periods of time during the four-year Saturn tour. To best match data rates with DSN coverage and telemetry performance requirements, rates at Saturn are planned between 128 kbits and 142 kbits/sec assuming 95% confidence of meeting a bit error requirement of 1×10^{-6} . A daily average of 4.1 S gigabits of Saturn tour science and engineering data is planned to be transmitted during a typical spacecraft pass over a 70-meter DSN station.

In January 1992, the Cassini telecommunications was accomplished by redundant 19-watt X-band traveling-wave tube amplifiers (X-TWTAs), redundant 9-watt Ka-Band TWTAs, and an Antenna Subsystem consisting of a 4-meter diameter High-Gain Antenna (HGA) with S-, X-, Ka-, and Ku-band (for the Cassini RADAR) feeds and two Low-Gain Antennas (LGAs) with X-band capability only. The operational plan was to employ the X-band during the cruise period while obtaining in-flight data on Ka-band characteristics and capabilities. When arriving at Saturn, the Ka-band would be employed exclusively for downlink data telemetry since it required less power to deliver approximately the same data volume as X-band. Redundant X-band transponders provided uplink receive capability and data/subcarrier-modulated RF drive to the transmitters.

Telecommunications Rescoped. The Cassini rescope in the spring of 1992 had significant effect on the telecommunications subsystems, but not on their capability to provide the commanding and telemetry functions originally required for science and engineering. One of the dual Ka-TWTAs was eliminated and the remaining transmitter was designated as a science element of the Radio Frequency Instrument Subsystem (RFIS) with carrier-only capability (no telemetry). This action sacrificed the functional redundancy inherent in the original baseline, but avoided the costly development of a high-reliability Ka-band transmitter. The two Remote Engineering Units (REUs) that interfaced the Ka-band capability to the CDS were also eliminated and replaced by command and telemetry interfaces between the Radio Frequency Subsystem (RFIS) and the ICS. The 4.15 gbits/day data return is still achievable as is the 500 bits/sec command rate. The pointing of the X-band HGA feed was retained as 3.14 mrad, and the Ka-band feed was "defocused" to provide 2.4 mrad half-power beamwidth for Radio Science. A block diagram of the present RFIS is shown in Fig. 11.

Additionally, the Ultra-Stable Oscillator (USO) was moved into the RFIS bay to provide improved service for the Radio Science Ka- and S-band downlink signals. The USO was also decoupled from the Doppler Wind Experiment, since it was determined that DWE could provide its own oscillator.

Information Subsystems (January 1992)

The spacecraft information subsystems perform five functions: uplink/commanding, spacecraft communications, telemetry, bulk data storage management, and spacecraft timing, and timing synchronization. These are implemented in both hardware and software although a majority of the functions are implemented in software. Prior to rescope all of the information system functions were to be developed prior to launch.

The primary subsystem of the information system is the CDS. Using the MIL-STD-1750A Engineering Flight Computer (EFC), the CDS receives ground commands and data from the RFIS, processes them, and distributes them to the other subsystems over a MIL-STD-1553B redundant data bus. It receives data from other on-board subsystems over the data bus, processes it, formats it for telemetry, and delivers it to the RFIS for transmission to Earth.

The original design for the uplink interface included the implementation of Consultative Committee for Space Data Systems (CCSDS) Command Operations Procedures Type One Standards (COP-1). This standard provides mechanisms for the automated transmission, verification, and retransmission of commands and data between the ground and the spacecraft.

an SSR. An SSR can be simultaneously accessed for read and write activities. One CDS string can alternate between SSRs but can (re) interface with a single SSR at a time. An SSR can be divided into a maximum of eight different telemetry data storage partitions, (act) of which is configurable to one of four different access modes. A CDS string can cycle between partitions for record and playback operations. The ordering of CDS record and playback operations between partitions and across SSRs is ground commandable. Before rescope full SSR partitioning and all SSR management software was to be implemented prior to launch.

Information Subsystems Rescoped. The Cassini information subsystems retain most of the functionality of the January 1 992 baseline. in the only hardware two science

modification, the three dual-redundant 1553B data buses were consolidated into one dual-redundant 1553B bus. The buses were deleted and science instrument bus users were added to the engineering bus. The combined science data collection bandwidth allocation on this remaining bus was reduced to 410 kilobits/sec.

The remaining changes have been in the software, where several functions were deferred or deleted. As the planning for system testing and mission operations has progressed, however, the project has found it necessary to reinstate some of this capability. The reason for the deferrals in the first place was cost savings, while the reasons for reinstatement have been risk mitigation or a realization, for some of them, that the function is required early in the mission. Table 1 summarizes the history of CDS flight software deferrals.

Table 1. CDS Flight Software Deferral History

RESCOPE DEFERRALS	ACTION SINCE RESCOPE	REASON FOR ACTION
COP-Up link protocols	Delete	Not required
Selected system fault protection monitors and responses	Reinstate	Mission risk
Critical sequence program type and critical sequence commands	Reinstate	Tight design coupling to reinstated system fault protection. Maybe required for launch sequence implementation.
Selected system services		
a) asynchronous intersubsystem data transfer	Reinstate	Needed for system fault protection.
b) ancillary data broadcast and collection	Reinstate	Simulation of this capability to support system test more costly than flight software development.
c) science house-keeping data packets	Reinstate	Unacceptable visibility into instrument performance during system test and early mission instrument checkout.
All but 5 telemetry modes	No change	
Support of all 8 downlink virtual channels	No change	
Full SSR partition management	No change	
Simultaneous dual CDS string recording of Critical telemetry data	No change	
Several uplink virtual channels	Delete	Only two are required: one hardware, one software.

Figure 13 illustrates the new AACCS block diagram with the deleted items shown in light gray.

To collect science data, the spacecraft must now time share between the remote sensing and the fields and particles observations. Slews for remote-sensing science will be

slower with maximum rates now at 0.26°/sec. The spacecraft will be required to operate in a slow roll mode (0.130/see to 0.260/see) for the fields and particles science observations and perform HGA down link simultaneously, such that spacecraft mass properly constraint are now imposed. Table II shows how these functions and their performances have changed in the redesign

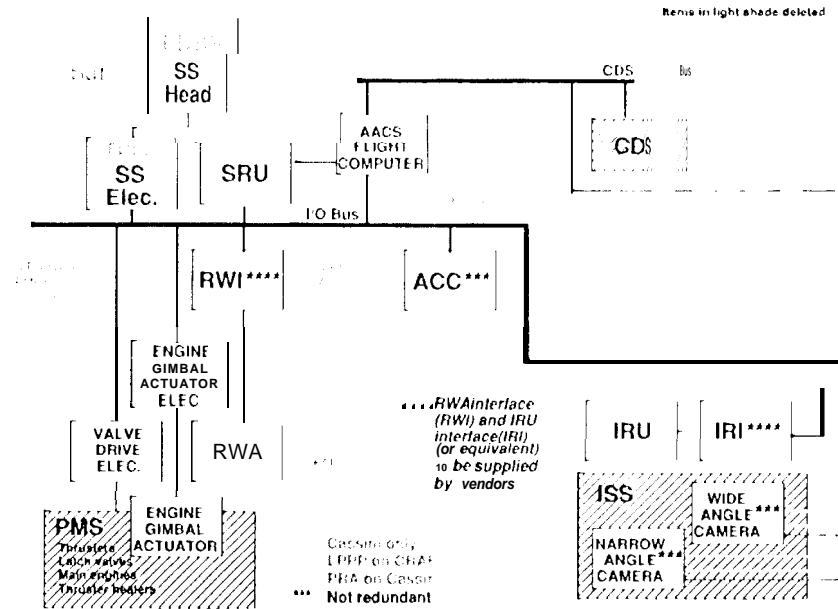


Fig. 13. Effects of Rescoping on the Cassini Spacecraft AACCS

Table 11. Spacecraft Control Functions Before and After Redesign

Function/Feature	CRAI/Cassini	Cassini Redesign
Ka-band (1IGA) Pointing	0.87 mrad	2.4 mrad (defocused Ka-band feed)
Basebody Control	Reaction wheels and thrusters	Same
Basebody Turn Rates on Thrusters	0.25 °/sec nominal, 0.4 °/sec available	Same
Star Sensing	Redundant wide-angle camera (2.8° FOV)	Redundant SRU (1 4.7° FOV)
Sun Sensing	0.010 accuracy	2° accuracy
Inertial Reference Unit (gyms)	on platform, drift 0.03°/hr	Basebody mounted, 1°/hr drift after 8 hrs since last calibration (more dependence on star tracker)
Remote Science Pointing Accuracy (inertia)	2 mrad	Same
Slew 0.34° (Narrow-Angle FOV)	10 sec	60-80 sec
Slew Wide-Angle FOV	10 sec for 2.8° FOV	3-4 min for 3.5° FOV (wide-angle camera FOV changed in redesign)
Fields & Particles and HGA Downlink	180/see (max)	0.26 °/sec (max, roll about spacecraft z-axis on reaction wheels with HGA pointed at Earth)
Stability	10 mrad/0.5 sec	Similar
Flare Data Relay	Dedicated antenna with single-axis articulation	Use HGA

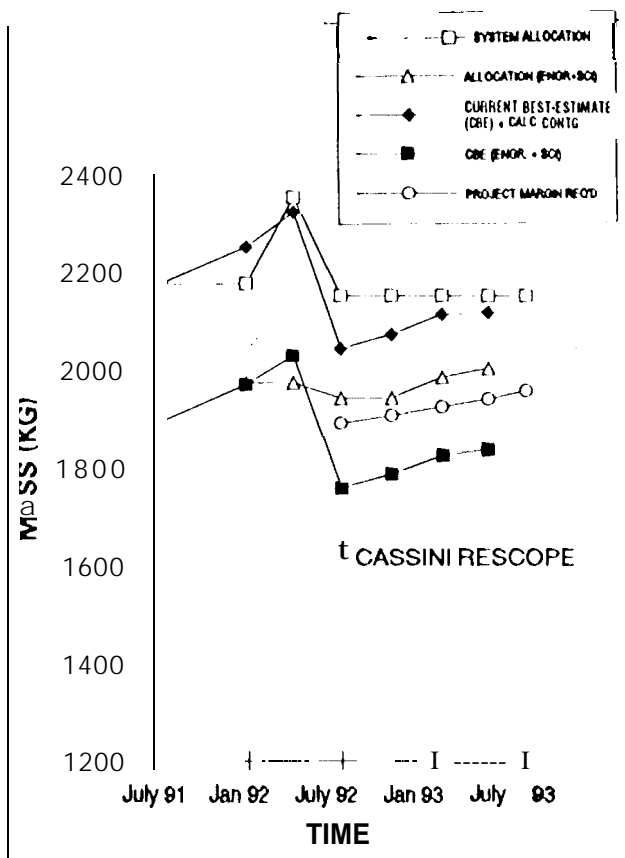


Fig. 14. Cassini Spacecraft Mass History

Operational Impacts

The most dramatic effect of the redesign on system operability is due to the loss of articulated science pointing. As on the Magellan spacecraft which points its radar at

Venus through programmed rotations of the entire system, Cassini must leave its normal line pointing and align instrument boresights to propagated inertial vectors computed onboard. During this time, spacecraft-to-Earth communications L case and the data are recorded on the Solid State Recorder. During a typical day in the Saturn tour, roughly fifteen hours are spent gathering mostly remote science data in this mode, followed by nine hours of playback combined with real-time fields and particles data. During the playback mode, the spacecraft rolls about the HGA axis. This daily "roll maneuver" recovers much of the data which the fields and particles instruments lost in spatial coverage when the Turntable was eliminated.

Summary and Conclusions

The restructuring of the Cassini Project was undertaken to strengthen its economic viability during a period of increasing budget pressures. All facets of the development phase were addressed during the study and savings were found in each. The resultant loss of some of the spacecraft system's functional redundancy has led to reduced operational flexibility and available observation time and to a reduction in the mission's data return. However, interfaces with the ESA-supplied T-lobe and the Probe itself have not been significantly altered and the complete complement of science instruments has been retained. The result is a mission that can perform more than ten times the science as the Voyager Saturn mission.

Additionally, the new mission is robust with respect to Titan IV launch performance, the spacecraft and science instrument capabilities are sufficient to accomplish the mission objectives, and the program costs have been reduced

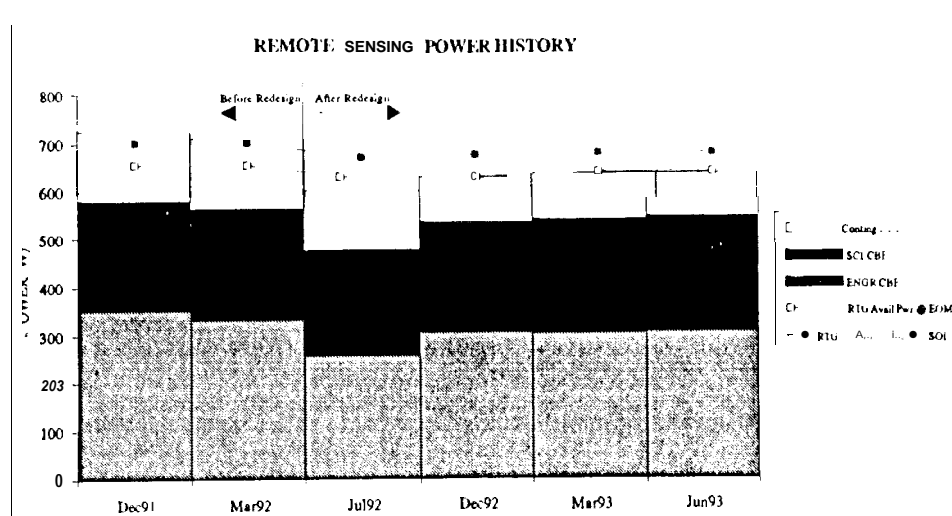


Fig. 15. Remote Sensing Power History