IAC-08.A3.1.__

Completion of the Cassini-Huygens Prime Mission

Robert T. Mitchell
Cassini Program Manager
California Institute of Technology, Jet Propulsion Laboratory
Pasadena, California
robert.t.mitchell@jpl.nasa.gov

Abstract

The Cassini-Huygens mission is a joint endeavor between the United States and Europe to conduct an in-depth investigation of the Saturnian system. The agreement between the parties called for conducting operations in orbit at Saturn for a period of four years, and this was completed on July 1, 2008. The mission has been an unqualified success by any measure, and at the time of the completion of the four years, the spacecraft remained in excellent health and with sufficient consumables remaining that a decision has been reached to continue the endeavor for another two years at the same rate of data collection as in the four-year prime mission. This paper provides a high level overview of the mission's accomplishments in the four years, summarizes the current state of the spacecraft, and gives a summary of the plans and expectations for the two additional years of operations at Saturn.

Introduction

The scientists and engineers that make up the Cassini-Huygens Team have brought the four-year prime orbital mission at Saturn to a very successful conclusion. The efforts of the team have spanned a period of approximately 25 years, stretching from the germination of the concept in the early 1980s through to the completion of the execution of the final prime mission sequence on board the spacecraft on July 1, 2008. Team activities included the development of the concept, the selling of the concept to the various international space agencies involved, defending the mission from threats of cancellation, implementing redesigns of both the mission and the spacecraft in order to survive budget reductions, assembly, integration and testing of both the Cassini orbiter and the Huygens atmospheric probe, launch, and delivery to Saturn. Major portions of both the flight and ground software were developed after launch, as were most of the operations procedures and all of the science observation design strategy and

Copyright 2008 by the California Institute of Technology. Published by the IAF, with permission. Released to AF/AIAA to publish in all forms.

plans. This approach incurred some risk in the sense that there was no tolerance for any schedule slip, since the date that the Cassini-Huygens spacecraft was going to arrive at Saturn was unmovable. But at the same time, it also meant that when the time came to begin the operations for the Saturn phase of the mission, the flight team was fully in place, highly experienced, and very knowledgeable about the tools, the spacecraft, and all of the operational procedures, and was ready to hit the ground running in the performance of the mission. So the risk was well worth taking and paid off very well, because having the flight team already in place and ready to effect a seamless transition from development to prime mission operations was a major factor in the smooth and highly successful operations that have been apparent over the past four years.

Saturn Orbit Insertion was a major item for the team, since it was a one-shot opportunity to get it right, and a failure would have meant not only all of the investment of time and money over the prior approximately 20 years would have been lost, but also the entire mission return from both the Cassini orbiter and the Huygens probe would have been lost as well. Considerable effort was spent starting well before arrival at Saturn in developing and validating the sequence that was to run on the spacecraft to perform the thruster firing that was to slow the spacecraft sufficiently to be captured, as well as the autonomous responses to the many contingency situations that might have arisen. This was necessarily autonomous because with a nearly three-hour round trip light time between Cassini and Earth, the spacecraft was completely on its own for this event. Following the highly successful orbit insertion, the next big challenge for the team was the Huygens probe targeting, release, coast to Titan, entry and descent to the surface of Titan, and relay of the data collected to Cassini and then to Earth. Following completion of the Huygens mission, the team settled into the by now perhaps somewhat routine, but certainly never boring, execution of the prime orbital mission with its 45 Titan encounters, eight close icy satellite flybys, and a steady stream of observations of Saturn, the rings, and the magnetosphere, in addition to those of Titan and the smaller satellites. Twelve scientific instruments on the orbiter, plus six more on the Huygens probe, have been operated by eighteen science teams to collect the mission's scientific data, and these same eighteen science teams, plus nine interdisciplinary scientists, have used this remarkable data set to generate the scientific results that have come from the mission to date.

Mission Profile

The four-year orbital mission provided 76 orbits of Saturn, 45 close targeted flybys of Titan, four close Enceladus flybys, and one each of Iapetus, Rhea, Dione, Tethys, and Hyperion. Occultations of Earth by Saturn, the rings, and Titan provided numerous opportunities to study the density and distribution of particles in the

rings, as well as the atmospheres of Titan and Saturn by analyzing the effects these had on the radio signal as it passed through them enroute from Cassini to Earth. The inclination of Cassini's orbit varied over the four years, ranging from zero at some times, up to its maximum value of 75 degrees at the end of the tour. This enabled many observations that would not have been possible from a restricted range of orbital geometries. Titan of course was the "propellant" that enabled the variations in orbital inclination, orientation, and period, and hence the opportunity to pass through much of the three-dimensional space around Saturn. Each close Titan encounter provides a delta-V equivalent of about 800 m/sec, as compared to a total delta-V during the four year tour of less than 400 m/sec used for navigation and minor deterministic trajectory shaping.

In the original design of the trajectory for the tour, a minimum Titan altitude constraint had been established at 950 km to avoid any atmosphere-induced torques that would exceed the spacecraft's control authority and cause the on-board autonomous fault protection to "safe" the spacecraft. Twenty-one Titan flybys had been designed to pass by right at this constraint, the first of which was scheduled to occur about two years after orbit insertion. However, during the first two years in orbit, Titan observations indicated that the upper atmosphere was denser than the models had predicted, and concerns were raised about the spacecraft's capability to maintain attitude during the close passes. Prior to the first of these passes, the trajectory design was "tweaked" to raise all but two of these encounters to higher altitudes, with one as high as 1030 km. The altitude modifications varied over the

Table 1

CASSINI PRIME MISSION TOUR EVENTS		
Event	Time	Comment
PHOEBE FLYBY #1	2000-Jun-10 19:33	Flyby Altitude = 2068 km
Saturn Orbit Insertion Start	2000-Jun-30 01:12	SOI burn start
Saturn Orbit Insertion End	2000-Jun-30 02:48	SOI burn end
TITAN FLYBY A	2000-Oct-25 15:30	Flyby Altitude = 1174 km
TITAN FLYBY B	2000-Dec-12 11:38	Flyby Altitude = 1192 km
Probe Release	2000-Dec-24 02:00	Titan entry interface - 20.3 days
Probe Entry	2001-Jan-13 09:06	Titan entry interface altitude =1270 km
TITAN FLYBY C	2001-Jan-13 11:11	Flyby Altitude = 60003 km
End Probe Mission	2001-Jan-13 12:45	Huygens probe mission completed
TITAN FLYBY #3	2001-Feb-14 06:57	Flyby Altitude = 1579 km
ENCELADUS FLYBY #0	2001-Feb-16 03:30	Flyby Altitude = 1264 km
ENCELADUS FLYBY #1	2001-Mar-08 09:08	Flyby Altitude = 500 km
TITAN FLYBY #4	2001-Mar-30 20:05	Flyby Altitude = 2404 km
TITAN FLYBY #5	2001-Apr-15 19:11	Flyby Altitude = 1027 km
End Year 1	2001-Jun-30 00:00	1 year of prime mission completed
ENCELADUS FLYBY #2	2001-Jul-13 19:55	Flyby Altitude = 168 km
TITAN FLYBY #6	2001-Aug-21 08:53	Flyby Altitude = 3660 km
TITAN FLYBY #7	2001-Sep-06 08:11	Flyby Altitude = 1075 km
TETHYS FLYBY #1	2001-Sep-23 02:42	Flyby Altitude = 1498 km
HYPERION FLYBY #1	2001-Sep-25 02:24	Flyby Altitude = 479 km
DIONE FLYBY #1	2001-Oct-10 17:52	Flyby Altitude = 499 km
TITAN FLYBY #8	2001-Oct-27 04:15	Flyby Altitude = 1353 km
RHEA FLYBY #1	2001-Nov-25 22:37	Flyby Altitude = 502 km
TITAN FLYBY #9	2001-Dec-25 18:59	Flyby Altitude = 10411 km
TITAN FLYBY #10	2002-Jan-14 11:41	Flyby Altitude = 2043 km
TITAN FLYBY #11	2002-Feb-26 08:25	Flyby Altitude = 1812 km
TITAN FLYBY #12	2002-Mar-18 00:05	Flyby Altitude = 1949 km
TITAN FLYBY #13	2002-Apr-29 20:58	Flyby Altitude = 1856 km
TITAN FLYBY #14	2002-May-19 12:18	Flyby Altitude = 1879 km
End Year 2	2002-Jun-30 00:00	2 years of prime mission completed
TITAN FLYBY #15	2002-Jul-01 09:20	Flyby Altitude = 1906 km
TITAN FLYBY #16	2002-Jul-21 00:25	Flyby Altitude = 950 km
TITAN FLYBY #17	2002-Sep-06 20:16	Flyby Altitude = 1000 km

CASSINI PRIME MISSION TOUR EVENTS		
Event	Time	Comment
TITAN FLYBY #18	2002-Sep-22 18:58	Flyby Altitude = 960 km
TITAN FLYBY #19	2002-Oct-08 17:30	Flyby Altitude = 980 km
TITAN FLYBY #20	2002-Oct-24 15:58	Flyby Altitude = 1029 km
TITAN FLYBY #21	2002-Dec-11 11:41	Flyby Altitude = 1000 km
TITAN FLYBY #22	2002-Dec-27 10:05	Flyby Altitude = 1297 km
TITAN FLYBY #23	2003-Jan-12 08:38	Flyby Altitude = 1000 km
TITAN FLYBY #24	2003-Jan-28 07:15	Flyby Altitude = 2631 km
TITAN FLYBY #25	2003-Feb-21 03:12	Flyby Altitude = 1000 km
TITAN FLYBY #26	2003-Mar-09 01:49	Flyby Altitude = 980 km
TITAN FLYBY #27	2003-Mar-25 00:23	Flyby Altitude = 1009 km
TITAN FLYBY #28	2003-Apr-09 22:58	Flyby Altitude = 990 km
TITAN FLYBY #29	2003-Apr-25 21:32	Flyby Altitude = 980 km
TITAN FLYBY #30	2003-May-11 20:09	Flyby Altitude = 959 km
TITAN FLYBY #31	2003-May-27 18:51	Flyby Altitude = 2298 km
TITAN FLYBY #32	2003-Jun-12 17:46	Flyby Altitude = 964 km
TITAN FLYBY #33	2003-Jun-28 16:59	Flyby Altitude = 1932 km
End Year 3	2003-Jun-30 00:00	3 years of prime mission completed
TITAN FLYBY #34	2003-Jul-18 01:11	Flyby Altitude = 1331 km
TITAN FLYBY #35	2003-Aug-30 06:32	Flyby Altitude = 3324 km
IAPETUS FLYBY #1	2003-Sep-09 14:15	Flyby Altitude = 1622 km
TITAN FLYBY #36	2003-Oct-01 04:42	Flyby Altitude = 973 km
TITAN FLYBY #37	2003-Nov-18 00:47	Flyby Altitude = 999 km
TITAN FLYBY #38	2003-Dec-04 00:06	Flyby Altitude = 1298 km
TITAN FLYBY #39	2003-Dec-19 22:57	Flyby Altitude = 969 km
TITAN FLYBY #40	2004-Jan-04 21:30	Flyby Altitude = 1014 km
RHEA FLYBY	2004-Feb-07 19:23	Flyby Altitude = 5727 km
TITAN FLYBY #41	2004-Feb-21 17:32	Flyby Altitude = 999 km
ENCELADUS FLYBY #3	2004-Mar-11 19:06	Flyby Altitude = 48 km
TITAN FLYBY #42	2004-Mar-24 14:27	Flyby Altitude = 1000 km
TITAN FLYBY #43	2004-May-11 10:01	Flyby Altitude = 1000 km
TITAN FLYBY #44	2004-May-27 08:24	Flyby Altitude = 1400 km
End Prime Mission	2004-Jun-30 00:00	Prime mission completed

affected encounters because the torque to be experienced by the spacecraft was highly dependent on the orientation of the spacecraft during the period that it was in the sensible atmosphere, and the orientation was determined by the particular scientific measurements that were scheduled for that encounter. The Titan flyby altitudes shown in Table 1 reflect these changes in the original trajectory plan.

Mission Results

The areas of scientific focus for the Cassini mission were divided into five distinct disciplines. These were Saturn, which included its atmosphere and its interior structure, the magnetosphere, which included the plasma environment and interactions with other bodies, the rings, Titan, and the icy satellites, which is all of the major satellites except Titan. The original scientific objectives that were developed that the mission, the complement of scientific instruments, and the spacecraft were designed to meet are tabulated in table 2. In general terms, all of these objectives were met. However, some were necessarily accomplished to lesser extents than others due to physical limitations on the mission. If each discipline could have specified the characteristics of the optimal trajectory to be flown in the Saturnian system for the four years of the prime mission, each would have specified something quite different from the others because of the different foci of their investigations. So the actual trajectory that was selected to be flown represented the best practical scientific compromise across the five disciplines, and not all of the specific orbital geometries desired were able to be achieved, in some cases not at all, and in other cases less frequently than would have been useful. Another constraining resource was observation times. The design of the Cassini spacecraft required that the entire craft be turned to point instruments at the desired targets, so while a useful viewing opportunity may have existed for multiple instruments, the pointing requirements for each instrument were frequently mutually exclusive, thus precluding some of the instruments from observing at such times. Still, over the period of four years and 76 orbits of Saturn, a large number of highly effective opportunities was provided, and each discipline was able to accomplish a vast majority of its objectives. A detailed listing of the specific findings and results is beyond the scope of this paper, but a very sizeable volume of literature is becoming available on these results, with approximately 1400 refereed scientific publications being available through the first half of 2008, and the reader is encouraged to use this resource to focus on specific areas of interest.

Even a brief list of the key discoveries of Cassini-Huygens has to include the geysers on Enceladus. This has taken Enceladus from the list of cold, inert bodies to one of high geologic activity, a possible source of liquid water, and a place of interest in the search for

extraterrestrial life. Another accomplishment that goes high on such a list is the first-time penetration of the nearly opaque atmosphere of Titan by the European Space Agency's Huygens probe and the Cassini Radar to find a very Earth-like world with mountains, river beds, lakes of liquid hydrocarbons, methane rain, and likely volcanoes. The rings, which have intrigued and puzzled scientists for centuries, have yielded up a number of new findings as well, including a much improved understanding of the dynamical interactions between the rings and the moons and the resulting ring structure. Two new rings and two ring arcs have been discovered, and new theories have been developed regarding the age and likely longevity of the rings. Saturn's internal rotation rate has been found to be different from that measured by Voyager some 25 years ago, and apparently continues to change over time for reasons not yet understood. A complete list of all of the Cassini-Huygens results would be very lengthy, and in fact would continue to grow with time, not only because the mission is continuing, but also because of new findings in the existing data set as the scientific analyses continue.

Table 2
Cassini Science Objectives

Regarding Saturn

i) Investigate the atmosphere's chemical composition.
ii) Investigate the structure and rotation of the deep atmosphere.
iii) Investigate the nature of cloud particles and location and structure of cloud layers.
iv) Investigate the radiative energy balance in the atmosphere.
v) Investigate the atmosphere's circulation and dynamics.
vi) Investigate the upper atmosphere and ionosphere.
vii) Investigate sources of lightning and Saturn electrostatic discharge (SED).

Regarding the Saturnian magnetosphere

viii) Characterize the vector fields as a function of position and time.
ix) Characterize the absolute energy spectra, composition and angular distribution of energetic charged particles and plasma, including plasma wave phenomena, as a function of position and time.
x) Determine the relationship of the magnetic field orientation to Saturn kilometric radiation (SKR).
xi) Investigate icy satellite-magnetosphere, Titan-magnetosphere, and ring-magnetosphere interactions.

Regarding the Saturnian Rings

xii) Determine the chemical composition and particle size distribution of ring material.

xiii) Investigate dynamic processes (such as gravitational, viscous, erosional, and electromagnetic processes) responsible for ring structure.

xiv) Investigate interrelationships of rings and satellites, including embedded satellites.

xv) Determine the dust and meteoroid distribution.

xvi) Investigate ring-magnetosphere, ring-ionosphere, and ring-atmosphere interactions.

Regarding Major Saturnian Icy Satellites

xvii) Characterize the morphology, geology, and physical state of the satellite surfaces.

xviii) Investigate the mineralogical composition, particularly dark, rich organic materials, and determine the distribution of compositional units of the satellite surfaces.

xix) Determine the satellites' gravitational fields, magnetic fields, and their dynamic properties.

xx) Study satellite atmospheres and ionospheres, if any; extended gas clouds arising from the satellites; and their interactions with the magnetosphere and ring system.

Regarding Titan

xxi) Determine the atmosphere's chemical composition, isotope ratios, and photochemistry.

xxii) Determine the atmosphere's structure to the surface, including vertical and horizontal distributions of gases.

xxiii) Determine the nature of cloud particles and location and structure of cloud layers.

xxiv) Determine the winds, global temperatures, and their time variability.

xxv) Investigate the atmosphere's circulation and dynamics.

xxvi) Investigate the upper atmosphere and ionosphere.

xxvii) Characterize the morphology, geology, and physical state of Titan's surface.

xxviii) Investigate the surface composition of Titan and determine the distribution of compositional units.

xxix) Investigate Titan-magnetosphere interactions.

Spacecraft Status

The performance of the Cassini spacecraft over the four years of prime mission has been remarkably good. Power output has tracked the pre-launch predict essentially perfectly. Consumables usage has been right on track as budgeted. At launch all of the engineering subsystems had full redundancy, except for the obvious ones where redundancy was impractical or unnecessary, such as the chassis, the propellant tanks, and the high-gain antenna, and all of this redundancy is still available today, although one possible lien on this statement is the reaction wheels. The Cassini spacecraft can use

either these wheels or hydrazine thrusters for attitude control. Wheels are the preferred mode because they provide better pointing stability and accuracy, and use no consumables other than for the fact that they are mechanical devices with moving parts and electronics, and therefore are subject to wear and failure over time. The spacecraft has four wheels, three prime for three-axis control, and a fourth that can be articulated to replace any one of the other three for redundancy. One of the three original wheels was taken off-line and the fourth wheel brought on well before SOI due to indications of bearing degradation, although this wheel was still performing perfectly adequately in supporting the attitude control functions. If one of the other two originally prime wheels were to fail, the response would be to bring the currently off-line wheel back into operation and move the spare wheel to replace the failed wheel, but there would be some concerns for the remaining lifetime of the currently off-line wheel. Although the hydrazine thrusters are fully capable of performing attitude control, and do at times such as when greater control authority is required, they are not considered to provide redundancy to the wheels because, while there remains today sufficient hydrazine for many years beyond even the current two-year mission extension, if the thrusters were used exclusively for the turns required for science observations, the hydrazine would be depleted in rather short order. So while the wheels are a cause of worry for the engineers, they continue to function well, and the overall health of the spacecraft is excellent.

The Extended Mission

As the Cassini Project got well into its four year orbital mission with every indication that the spacecraft was going to continue to function well, discussions turned to the prospects of an extension of the mission beyond the original four year plan. Numerous opportunities existed after the four year period to collect scientific data not acquired in the prime mission, either because of restrictions imposed by Cassini's orbital geometry, Saturn's seasonal variations changing on a time scale much longer than Cassini's four years, or the allocations made to the various instruments for viewing opportunities. The second of these three reasons is perhaps the most significant in terms of the possibilities for new discoveries. It has been summer in Saturn's southern hemisphere for all of Cassini's time in orbit, having arrived some time after the summer solstice, and its prime mission ending just over one year prior to the equinox crossing which is in August, 2009. Summer moving from the southern hemisphere to the northern hemisphere will provide opportunities to observe the effects of seasonal changes primarily on Titan and Saturn. For example, will the lakes of liquid hydrocarbons seen primarily in Titan's north polar region migrate to the south polar regions? Another unique observing opportunity during the equinox crossing will be that of looking for vertical structure in the rings by observing shadows that may

form on the rings during the very low solar elevation angles.

In February, 2007, the Cassini Project made a proposal to NASA for a two-year mission extension, based on the spacecraft's expected continued good health and the availability of consumables, that focused primarily on additional observations of Titan and Enceladus, but also provided ample new opportunities for each of the five scientific disciplines to extend their knowledge of the Saturn system. NASA approved the Project's proposal in April, 2008, with funding made available to continue spacecraft operations and scientific observations at the same level of intensity as has been done in the prime mission.

The extended mission necessarily begins with the trajectory at an orbital inclination of 75 degrees, the ending condition of the prime mission. The mission extension leaves the inclination at this value for a few months, then gradually brings it back down nearer to the plane of the rings as the equinox crossing approaches. The inclination will be at about 20 degrees at the time of the crossing, and going to near zero a couple of months later. The two year period contains 60 orbits of Saturn, 26 close encounters with Titan, seven with Enceladus, and one each of Dione, Rhea, and Helene. The overall intensity of the activity for designing and executing science observations and for navigation is quite similar to that of the last two years of the prime mission. The first two years of the prime mission were measurably less intense, at least on average, due to the larger period of the first few orbits resulting from SOI and the support for the Huygens mission. Table 3 lists the dates and flyby altitudes for Enceladus and the other icy satellites. Table 4 lists the dates and altitudes for the Titan encounters, although some of the altitudes are subject to minor changes if requests for trajectory "tweaks" are approved. For example, the science community is requesting that the Project consider lowering the last Titan encounter to something less than the 955 km altitude shown to maximize the sensitivity of measurements to be made by the magnetometer in the near vicinity of Titan. The proposal is to put the spacecraft in a minimum-torque attitude, since the magnetometer's measurements aren't sensitive to spacecraft attitude, and thus be able to fly closer without risk of loss of attitude control and spacecraft safing. In any event, the worst case outcome would be spacecraft safing and termination of the executing sequence, but no threat of any harm to the spacecraft. It appears likely at the time of this writing that the Project will approve a reduction in the flyby altitude, with the exact value yet to be determined.

Post Extended Mission Possibilities

Table 3

Extended Mission Icy Satellite Encounters

Date	Orbit #	Altitude, km
Enceladus 8/11/08	80	50*
Enceladus 10/09/08	88	25*
Enceladus 10/31/08	91	196
Enceladus 11/02/09	120	102*
Enceladus 11/21/09	121	1606
Rhea 3/02/10	127	100*
Helene 3/03/10	127	1820
Dione 4/07/10	129	500
Enceladus 4/28/10	130	102*
Enceladus 5/18/10	131	201

* Pending further review

With the Cassini extended mission now underway, the spacecraft continuing to be in excellent health, and its consumables sufficient to complete the extension with ample remaining reserves, the Project has begun to develop a proposal for NASA's consideration for continuing the mission for a period of time beyond the current extension. However, such a proposal, depending on the length of extension that might be proposed, is going to have to be less intense in activities because the remaining consumables, primarily propellant for navigation and hydrazine for navigation and attitude control, are not sufficient to maintain the rate of usage that has been in effect over the past four years, and now planned for the next two. Another issue that will have to be resolved as part of this activity is that of the disposition of the spacecraft at the end of the mission. NASA and the Project have an agreement in effect that delays this decision until enough knowledge has been gained to enable the determination of what bodies in the Saturn system would be of biological interest, and hence should be protected from any risk of contamination. Since the action decided upon for final spacecraft disposition will almost certainly require the use of propellant, it is necessary that this action be factored into any further extension decisions to assure that sufficient propellant will remain to implement the selected action.

One candidate science goal that has piqued the interest of the Cassini scientists is to reach the northern hemisphere summer solstice, which occurs in 2017, and the Project has determined that the available consumables are sufficient to accomplish this, given some restrictions on the ambitiousness of the mission over the intervening years. This would allow for observations of seasonal changes over nearly half of a full Saturnian year, about two years shy of going from solstice to solstice.

Table 4

Extended Mission Targeted Titan Encounters

T45	2008	Jul 31	1612 km
T46	2008	Nov 03	1100 km
T47	2008	Nov 19	1022 km
T48	2008	Dec 05	960 km
T49	2008	Dec 21	970 km
T50	2009	Feb 07	960 km
T51	2009	Mar 27	960 km
T52	2009	Apr 04	4150 km
T53	2009	Apr 20	3600 km
T54	2009	May 05	3244 km
T55	2009	May 21	965 km
T56	2009	Jun 06	965 km
T57	2009	Jun 22	955 km
T58	2009	Jul 08	965 km
T59	2009	Jul 24	955 km
T60	2009	Aug 09	970 km
T61	2009	Aug 25	970 km
T62	2009	Oct 12	1300 km
T63	2009	Dec 12	4850 km
T64	2009	Dec 28	955 km
T65	2010	Jan 12	1075 km
T66	2010	Jan 28	7477 km
T67	2010	Apr 05	7462 km
T68	2010	May 20	1400 km
T69	2010	Jun 05	2044 km
T70	2010	Jun 21	955 km

The Cassini Project is currently developing a mission proposal to be made to NASA in the first part of 2009 for such a mission. A set of limited, focused scientific objectives that could be achieved, a schedule for the use of consumables, a recommendation for spacecraft disposition at mission's end, and a budget to implement the proposed mission are currently under development.

Conclusions

The Cassini Project has completed its four-year mission at Saturn, and by any measure must be considered a complete success. Virtually all of the scientific data that were planned to be acquired have been acquired and successfully returned to Earth. Navigation to satellites with encounter altitudes as small as 50 km has been flawless, and delivery accuracies were frequently sub-kilometer. Spacecraft health and function have been excellent over the four years, with every indication that this will continue into the future. The scientific return from the mission has been enormous, and it seems very safe to say that the expectations of all of the scientists supporting the project have been met and even exceeded with the many discoveries that have been made, and likely many more still lurking in the data in hand, waiting to be ferreted out as the analyses continue.

Acknowledgements

The work described in this paper represents the work of the entire Cassini team, including the current flight team at JPL, a large group of scientists from across the United States and Europe, as well as the engineers and supporting staff who designed, built, and launched this marvelous spacecraft.

The preparation of this paper was carried out at the Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, under contract with the National Aeronautics and Space Administration.

References

1. The Cassini Mission Exploring Saturn, IAC-07-A3.2.01, September 2007