The Cassini Solstice Mission: Streamlining Operations by Sequencing with PIEs

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The Cassini Solstice Mission (CSM) is the second extended mission phase of the highly successful Cassini/Huygens mission to Saturn. Conducted at a much-reduced funding level, operations for the CSM have been streamlined and simplified significantly. Integration of the science timeline, which involves allocating observation time in a balanced manner to each of the five different science disciplines (with representatives from the twelve different science instruments), has long been a labor-intensive endeavor. Lessons learned from the prime mission (2004-2008) and first extended mission (Equinox mission, 2008-2010) were utilized to design a new process involving PIEs (Pre-Integrated Events) to ensure the highest priority observations for each discipline could be accomplished despite reduced work force and overall simplification of processes. Discipline-level PIE lists were managed by the Science Planning team and graphically mapped to aid timeline deconfliction meetings prior to assigning discrete segments of time to the various disciplines. Periapse segments are generally discipline-focused, with the exception of a handful of PIEs. In addition to all PIEs being documented in a spreadsheet, allocated out-of-discipline PIEs were entered into the Cassini Information Management System (CIMS) well in advance of timeline integration. The disciplines were then free to work the rest of the timeline internally, without the need for frequent interaction, debate, and negotiation with representatives from other disciplines. As a result, the number of integration meetings has been cut back extensively, freeing up workforce. The sequence implementation process was streamlined as well, combining two previous processes (and teams) into one. The new Sequence Implementation Process (SIP) schedules 22 weeks to build each 10-week-long sequence, and only 3 sequence processes overlap. This differs significantly from prime mission during which 5-week-long sequences were built in 24 weeks, with 6 overlapping processes.

I. Introduction

Cassini is a flagship mission that reached the Saturnian system in 2004, following its launch in 1997. The 12 science instruments onboard have made many new discoveries about Saturn and its magnetosphere, the rings and ring moons, Titan, and the icy satellites. A description of the mission and the prime mission science planning and operations can be found in past SpaceOps papers from 2004[1] and 2006[2]. The prime mission for Cassini ended in 2008, and a follow-on Cassini Equinox Mission (CEM) in fall 2010. The Equinox mission was so named because Saturn reached its spring equinox relative to the Sun, aligning the rings in Saturn's equatorial plane for the first time in 16 years

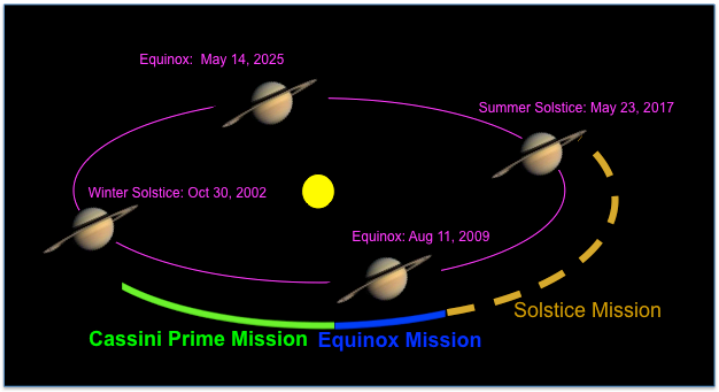

Figure 1. The phases of the Cassini mission to Saturn.

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(figure 1). The logical follow-on mission was thus the Cassini Solstice Mission (CSM), keeping Cassini active at Saturn until the Saturnian summer solstice in mid 2017. This will allow a full cycle of ring illumination angles to be explored and analyzed by the comprehensive suite of Cassini instruments..

Being an extended mission, the budget available was reduced from prime mission levels. Science instrument, science operations, and spacecraft operations teams all investigated what could be accomplished at 50% and 75% levels of prime mission funding. The final, accepted proposal to NASA headquarters involved a 40% cut in engineering support operations and a 25% reduction for the science teams. With these reductions, changes needed to be made in the way that science was both integrated and implemented.

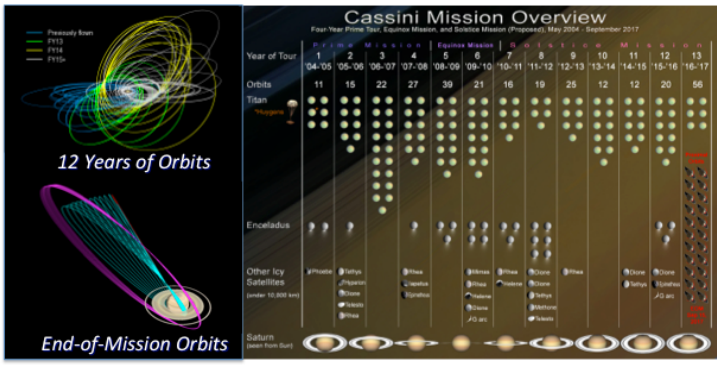


Figure 2. Orbit geometry and mission overview.

II. Prime Mission

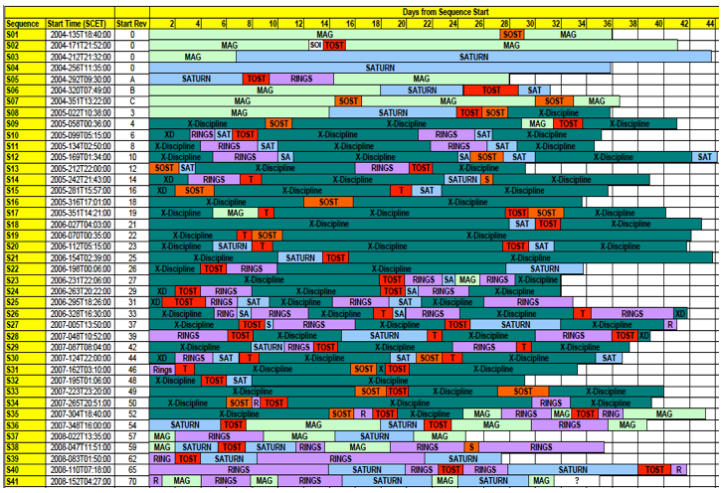


Figure 3. Prime mission segmentation results.

Prime mission tour design and selection took place during the 6 year cruise to Saturn. The discipline working groups (Titan, Icy Satellites, Rings, Saturn, and Magnetospheres) worked with Project Science and the navigation team to come up with a tour satisfying the primary science requirements of each discipline. The prime mission at Saturn (2004-2008) consisted of 45 targeted Titan flybys and 13 of the icy satellites spread over 4 years, with an average of 19 periapses per year (figure 2).

Segmentation for prime mission was accomplished at a 5 day science workshop, with representatives from each discipline physically present to argue for ownership of each periapse segment of time (figure 3) (apoapse time segments were generally given to a cross-discipline group). Some periapse segments were desired by multiple disciplines, and a "liens list" was established to record when one discipline would receive observation time in a segment awarded to a different discipline. Each discipline then met weekly to integrate their segments, with representatives from other disciplines present to request observation time and ensure liens were integrated.

III. Equinox Mission

Equinox mission tour design was performed in 2006-2007 and followed a similar pattern to prime mission tour selection, albeit in a shorter time frame. Despite being only 2 years in length, a further 26 Titan targeted flybys and 12 of icy satellites made the final tour; the first year had 39 periapses and the second year 21 periapses. Once again the disciplines argued over which periapse would go to which discipline, and a liens list was established. As funding levels remained the same as for the prime mission, no reductions in either operations or science teams were necessary; in fact the large number of periapses made this time period busier for the operations teams than during prime mission. Integration meetings were still held weekly by each discipline.

IV. Solstice Mission

With the Solstice mission lasting a further 7 years, and with a reduced level of operations funding, it was apparent that the old method of segment allocation and integration would not be feasible. The science planning manager at JPL was tasked with developing a new allocation method that would allow each discipline to meet their priority 1 science goals with reduced operations costs and eliminate the need for tracking liens over a 7 year span.

While partially simplified by going to longer orbit periods, there were still 12 to 25 periapse periods per year (not counting the final year's F-ring/proximal orbits, which are currently undergoing their own allocation process), with multiple disciplines having priority 1 science opportunities on many of the orbits.

A. Sequence Process Changes

As part of the operations team reduction, two changes to the sequence implementation process (SIP) were made; reducing the number of overlapping sequence development processes to 3 (down from 6 during the Prime and CEM mission phases), and to lengthen the sequence execution period from 5 weeks on average to 10.

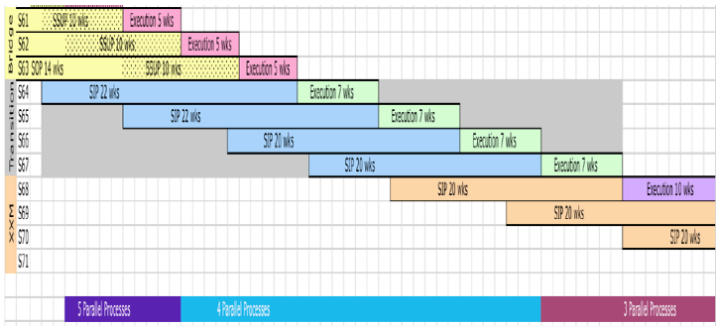


Figure 4. Sequence implementation process changes.

To smoothly transition to the new SIP schedule, a 4-sequence "bridge" period was defined at the end of CEM/beginning of CSM that gradually increased the sequence length from 5 weeks to 10 weeks and decreased the number of overlapping processes (figure 4).

The SIP schedule also allows time for the spacecraft engineering team to tweak science pointing designs to minimize the possibility of the aging reaction wheels sticking while spinning too slowly; a reaction wheel bias optimization tool (RBOT) points out problem areas, and science teams work with the engineers to modify designs.

B. Segmentation Process Changes

The newly designed segmentation process was also first introduced for the bridge sequences. These sequences had a total of 4 periapses within 18 Rs (Saturn radii). For all of CSM excluding the F-ring and proximal orbits, there are a total of 112 periapses within 18 Rs. The total time within 18 Rs was 9552 hours. Knowing that downlink time and engineering activities are also required, and to not overallocate the time in advance, it was decided to allow 400 hours each to the four discipline groups (Rings, Saturn, Magnetospheres, and Icy Satellites) that have the majority of their priority observations near periapse. These high priority desired observations were named PIEs, for Pre-Integrated Events. The Titan discipline is different; the Titan flybys occur outside of 12 Rs and so they are often not in conflict with other high priority science. Targeted Titan flybys accounted for 284 hours within 18 Rs, so they were given a further 116 hours of PIE time to use outside of the targeted flybys.

This total of 2000 hours of PIE time represents about one-third the available observation time, which allowed for the possibility of additional workforce savings due to this reduced activity level..

Since the bridge sequence PIE process was performed first, teams understood that any bridge PIE hours would be subtracted from the 400 total hours allowed for CSM. The desired PIEs from all disciplines were then plotted using an in-house graphic timeline program that showed the observations as well as downlink time periods and geometrical events (figure 5). A series of segmentation meetings were held to deconflict the PIEs amongst the 4 discipline working groups. A second round was performed to make up for the PIE hours lost in the deconfliction process. No discipline used more than 25 PIE hours in the bridge segments. The final, agreed to PIE lists were then published, and two further meetings were held to perform segmentation of the bridge segments.

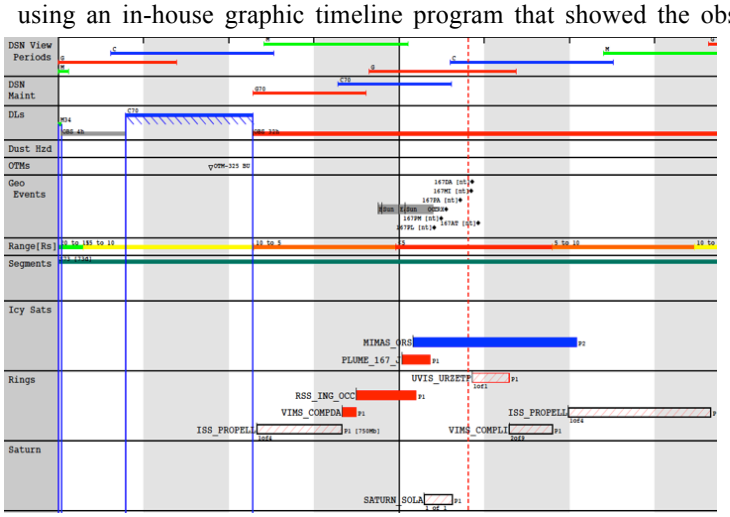
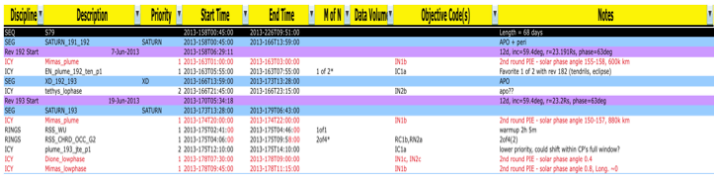


Figure 5. PIEs requested in one periapse segment.

While one of the original goals of simplification for CSM was to have single-discipline periapse periods, it was soon apparent that much valuable science would be lost by strictly adhering to this plan. Instead discipline-focused periapse periods were established in which up to 3 PIEs were allowed of out-of-discipline science. Segmentation was a quick

process due to the new PIE process; it was usually very apparent which discipline should lead the integration of a periapse based on the PIEs alone.



Discipline	Description	Priority	Start Time	End Time	M of N	Data Volume	Objective Code(s)	Notes
SEG	S79		2013-158T00:45:00	2013-159T23:31:00				Length = 68 days
SEG	SATURN_191_192	SATURN	2013-158T00:45:00	2013-166T13:59:00				APO + peri
Rev 192 Start	7-Jun-2013		2013-158T06:29:11					12d, inc=59.4deg, r=23.191Rs, phase=63deg
ICY	Mimas_plume		1 2013-163T01:00:00	2013-163T03:00:00			IN1b	2nd round PIE - solar phase angle 155-158, 600k km
ICY	Eth_plume_192_ten_p1		1 2013-163T05:55:00	2013-163T07:35:00	1 of 2*		IC1a	Favorite 1 of 2 with rev 192 (tendrils, eclipse)
SEG	XD_192_193	XD	2013-166T13:59:00	2013-173T13:28:00				APO
ICY	tethys_lophase		2 2013-166T21:45:00	2013-166T23:15:00			IN2b	apo??
Rev 193 Start	19-Jun-2013		2013-170T05:34:18					12d, inc=59.4deg, r=23.2Rs, phase=63deg
SEG	SATURN_193	SATURN	2013-173T13:28:00	2013-179T06:43:00				
ICY	Mimas_plume		1 2013-174T20:00:00	2013-174T22:00:00			IN1b	2nd round PIE - solar phase angle 150-157, 880k km
RINGS	RSS_WU		1 2013-175T02:41:00	2013-175T04:46:00	1of1			warmup 2h 5m
RINGS	RSS_CHRD_OCC_G2		1 2013-175T04:06:00	2013-175T09:58:00	2of4*		RC1b,RN2a	2of4(2)
ICY	plume_193_ite_p1		2 2013-175T12:10:00	2013-175T14:10:00			IC1a	lower priority, could shift within CPs full window?
ICY	Dione_lowphase		1 2013-178T07:30:00	2013-178T09:00:00			IN1c, IN2c	2nd round PIE - solar phase angle 0.4
ICY	Mimas_lowphase		1 2013-178T09:45:00	2013-178T11:15:00			IN1b	2nd round PIE - solar phase angle 0.8, Long. ~0

Figure 6. Portion of final PIE list.

The final PIE list (figure 6) was published as an Excel spreadsheet. However, to avoid the possibility of an out-of-discipline PIE being missed during integration, deadlines were established for these PIEs to be pre-entered into the Cassini Information Management System (CIMS), a database used by Cassini science planning engineers to manage individual segments as well as sequence builds. In this way, discipline based segment integration could be performed easily without involving representatives from the other disciplines. Integration meetings were reduced from weekly to monthly (or less) per discipline.

This new PIE process was then repeated for the remaining CSM, excluding the F-ring and proximal orbits. Each of the four disciplines now had 400 hours of PIE time for their initial desired observations, minus the hours used in the bridge segments. Four PIE deconfliction meetings were needed for the first round, and second-round PIEs were awarded in two follow-on meetings. Segmentation was again easy to perform, with a few lessons learned from the bridge sequences taken into account:

1) Many periapse periods were comprised of more than one observation period, with an intervening downlink pass. Nomenclature was borrowed from the Titan integration team in which an observation period preceding the main one was an "engine" while one following the main period was a 'caboose". Due to restrictions on the use of the large 70 meter DSN antennas, caboose periods were not desired by several of the discipline integration teams, and for CSM these were passed on to the following cross-discipline apoapse segment.
2) While the PIEs were meant to take place within 18 Rs, some discipline's priority science occurred outside of this range. The Saturn discipline in particular desired a dedicated apoapse period every 6 months. These became known as CAKEs (Cassini ApoKrone Exploration). The Magnetospheres discipline also received dedicated apoapse segments periodically.
3) Even though the Titan dedicated flybys were all awarded to the Titan discipline without question, they did require some observing time outside of these flybys. Titan cloud monitoring observations were allowed as non-PIE, out of discipline science because their pointing was flexible and did not complicate the reaction wheel speed optimization process.

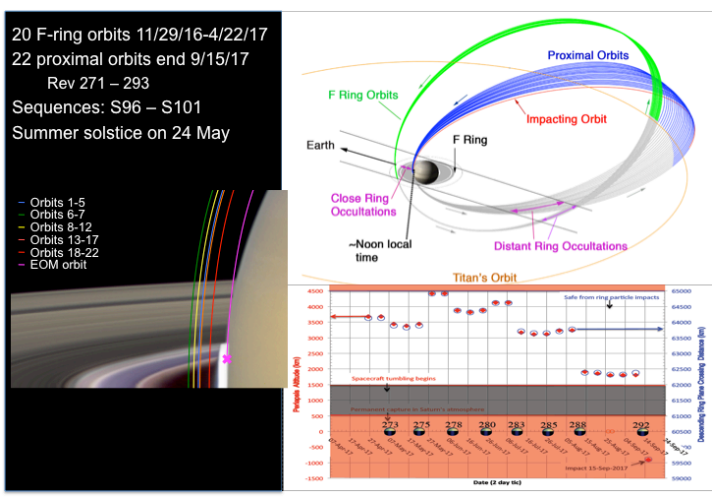


Figure 7. F-ring and proximal prbits overview.

V. Conclusion

Despite reduced staffing and an aging spacecraft, these changes to the segmentation, integration, and implementation processes have enabled the Cassini Solstice Mission to continue to near-optimize the science returned from all 5 disciplines. The final year of the mission (November 2016-September 2017) presents new difficulties; the F-ring and proximal orbits are largely ballistic, with certain observation types having much higher priority than others. The segment allocation process will be further refined as a result, with PIEs again used as part of the integration process. This process will occur in Fall 2014. In addition orbital geometries cause excessive heating and boresight pointing issues. Working groups[3] are currently addressing these issues to ensure Cassini maximizes its science return from this one of a kind mission..

Acknowledgments

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References

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