Cassini Titan Science Integration: Getting a "Jumpstart" on the Process

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The Cassini spacecraft has been in orbit for five years, returning a wealth of scientific data from Titan and the Saturn system. The mission is a cooperative undertaking between NASA, ESA and the Italian Space Agency and the project is currently planning for a second extension of the mission. The Cassini Solstice Mission (CSM) will extend the mission's lifetime until Saturn's northern summer solstice in 2017. The Titan Orbiter Science Team (TOST) has the task of integrating the science observations for all 126 targeted Titan flybys (44 in the Prime Mission, 26 in the first extension (Equinox Mission), and 56 in the second extension (Solstice Mission)) contained in the chosen trajectory. Cassini science instruments are body-fixed with limited ability to articulate; thus, the spacecraft pointing during the flybys must be allocated among the instruments to accomplish the mission's science goals. The science that can be accomplished on each Titan flyby also critically depends on the closest approach altitude, which is in turn determined by the attitude, but changing the altitude impacts the overall trajectory for the Solstice Mission. During the Prime and Extended missions, TOST has learned that the best way to achieve Cassini's Titan science goals is via a "jumpstart" process prior to final delivery of the trajectory. The jumpstart is driven by the desire to balance Titan science across the entire set of flybys during the CSM, and to influence any changes (tweaks) to the flyby altitudes. By the end of the jumpstart, TOST produces Master Timelines for each flyby, identifying each flyby's prime science observations and allocating control of the spacecraft attitude to specific instrument teams. In addition, developing timelines early, while the science and operations teams are still fully funded, decreases the future workload in integration and implementation.

Nomenclature

CSM	=	Cassini Solstice Mission
IDS	=	Interdisciplinary Scientist
MAPS	=	Magnetospheric and Plasma Science
OST	=	Orbital Science Team
PSG	=	Project Science Group
SOST	=	Satellites Orbital Science Team
TOST	=	Titan Orbital Science Team
TWT	=	Target Working Team

I. The Mission, Spacecraft, and Instruments

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The Cassini-Huygens mission to Saturn is a collaborative effort of NASA, ESA, and the Italian Space Agency[2]. The spacecraft launched on October 15, 1997 on a Titan IV-B/Centaur launch vehicle. After seven years, 3.2 billion kilometers (2 billion miles), and 4 gravity-assist flybys of other planets, it entered orbit on July 1, 2004. The spacecraft studied the planet, its rings, and its magnetosphere over the course of 76 varied orbits in the prime and extended mission. To study Saturn's satellites, the spacecraft made targeted flybys of Pheobe, Hyperion, Dione, Rhea, and Iapetus, along with 3 flybys of Enceladus, and 45 of Titan. In summary, the Cassini prime mission was the most complicated gravity assist tour ever flown.[1] The Cassini Orbiter also carried along the Huygens probe, destined to measure Titan's atmosphere *in situ* and land on Titan's surface. The probe was deployed on December 25, 2004. Three weeks later, on January 14, 2005, it entered Titan's atmosphere and landed on the surface 2 hours later. The probe sent measurements and images to Cassini for transmission to Earth.

The spacecraft communicates with Earth largely through one high gain antenna but also carries two low gain antennas. Three radioisotope thermal electric generators provide power.

Cassini's twelve science instruments are grouped into three categories: Optical Remote Sensing, Fields/Particles/Waves, and Microwave Remote Sensing. The Optical Remote Sensing suite is comprised of a visible wavelength imaging camera (ISS), an ultraviolet imaging spectrometer (UVIS), and infrared spectrometers (Cassini Infrared Spectrometer, or CIRS) and cameras (VIMS). The Fields/Particles/Waves suite is comprised of a magnetometer (MAG), cosmic dust analyzer (CDA), Radio and Plasma Wave system (RPWS), ion and neutral mass spectrometer (INMS), plasma spectrometer (Cassini Plasma Spectrometer, or CAPS), and a magnetospheric imaging instrument (MIMI). The Microwave Remote Sensing suite is comprised of RADAR and the Radio Science Instrument, both of which use the high-gain antenna as an instrument.

Figure 1 identifies the science instruments and the locations of the distributed operations center for each instrument. The Cassini mission requires operations on a global scale, and multiple time zones. In the final spacecraft configuration, the instruments were all mounted to the body of the spacecraft instead of a scan platform, which posed the single greatest challenge to operation complexity. The entire spacecraft must be rotated for any one instrument to achieve a desired target, and then the entire spacecraft must be rotated to point the high-gain antenna to earth to downlink the collect data. However, he optical remote sensing instruments are roughly co-aligned so they can often collect data collaboratively. On a typical Titan flyby the spacecraft collects science data for 30-40 hours by pointing the spacecraft at a variety of targets. One instrument at a time controls the pointing of the spacecraft, and other instruments may "ride along" and collect data at the same time if the data is useful to them. There are some operational restrictions to riding along; for instance, the two Microwave Remote Sensing instruments (RADAR and Radio Science) are both major power consumers and cannot be operated simultaneously.

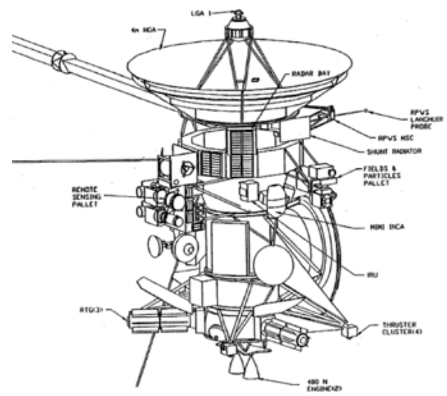

Figure 1. The Cassini Spacecraft.

The Cassini Project recently completed tour planning for an additional 7-year phase called the Cassini Solstice Mission (CSM) that will extend the mission lifetime through Saturn's northern summer solstice. This extension permits observations of seasonal change across nearly half a Saturnian year (see Fig. 2).

II. How Cassini Plans Science

The process to plan CSM science started in January 2009 with the selection by the Cassini Project Science Group (PSG) of a trajectory. This group, which meets three times a year, is made up of the Principal Investigators of the 12 science instruments, interdisciplinary scientists, science planners, and various scientists from each instrument. Navigation engineers designed multiple trajectories that attempted to meet all the science objectives that the PSG selected for the CSM, targeting the planet, its rings, magnetosphere, icy moons, and Titan. Once the trajectory was selected there was a very short period of three months during which the science community could request small changes ("tweaks") to the trajectory to improve science opportunities. The navigators accomodated these changes where possible. The PSG evaluated this revised trajectory, looking at how the proposed changes affected overall science opportunities and propellant use. Following this evaluation, the PSG decided which tweaks would become part of the final, official trajectory, named SM-7a[3].

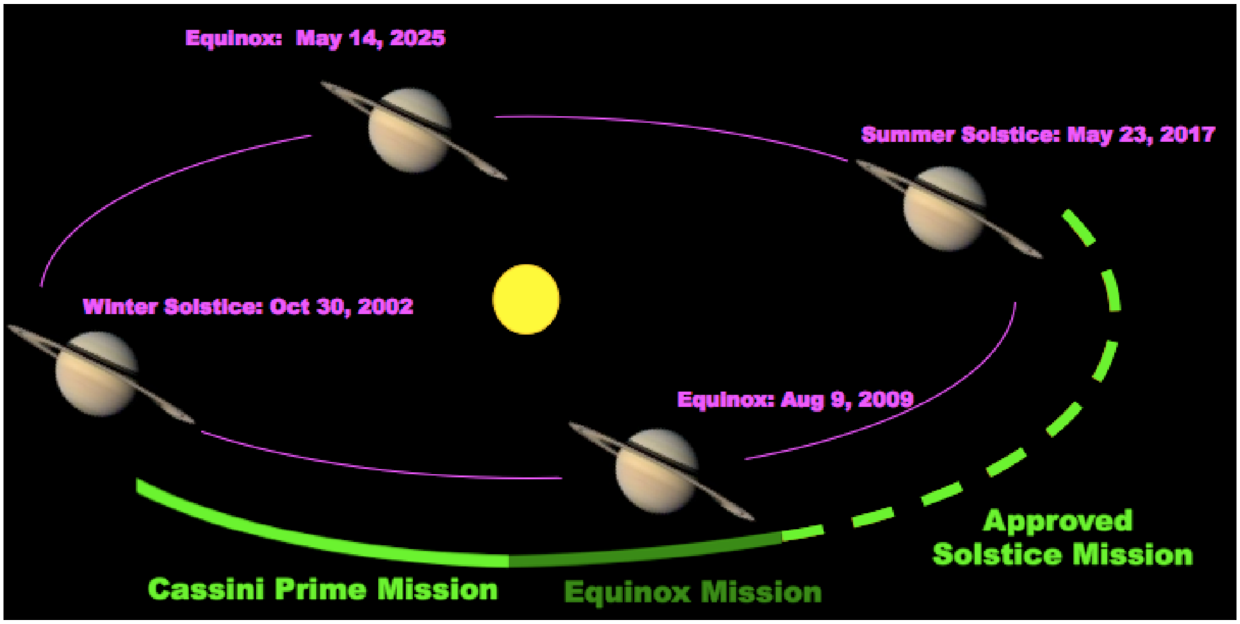

Figure 2. Phases of the Cassini Mission. The Cassini Prime Mission ran from just after winter solstice to just before Equinox. The Equinox Mission was centered on Equinox; the Solstice Mission will last until Saturn's summer solstice.

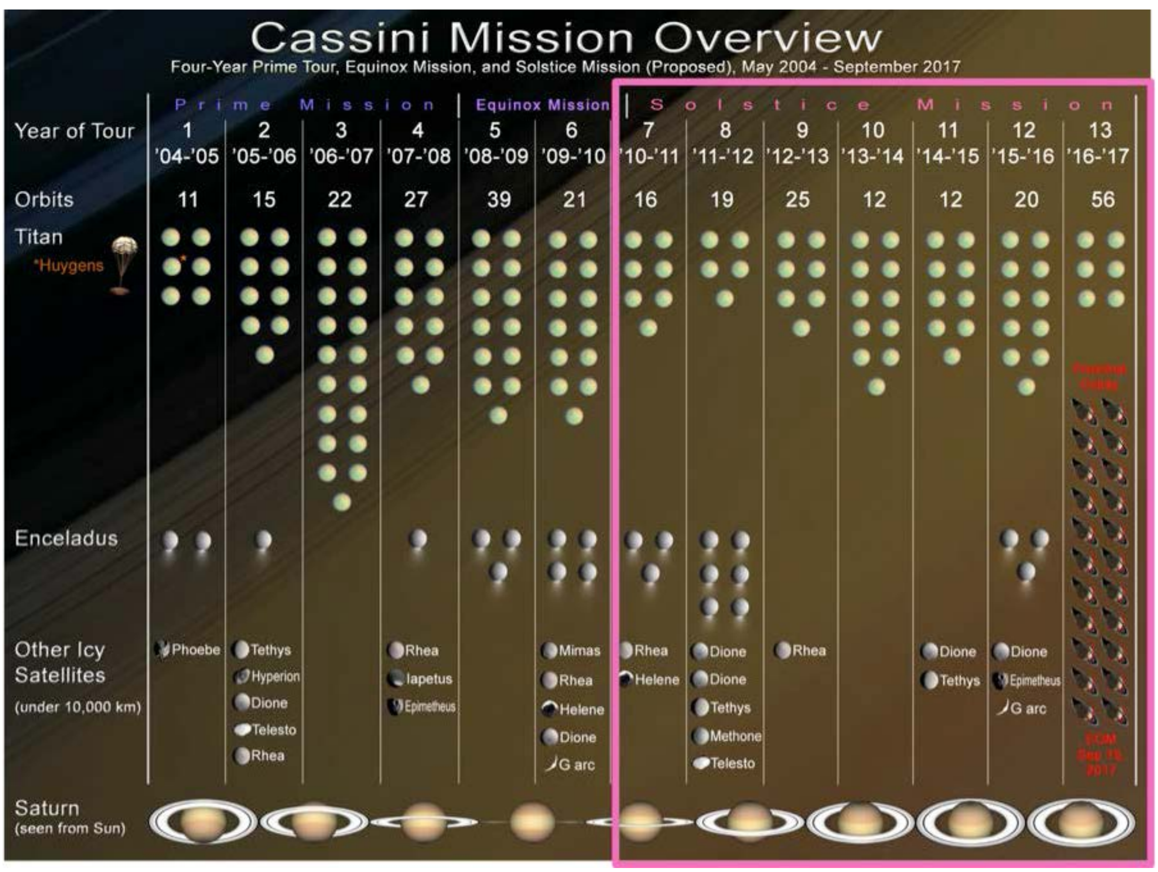

Figure 3. Cassini Mission Overview. A yearly summary of the number of orbits and flybys for the entire mission from 2004 through 2017. Figure courtesy David Seal, NASA/JPL

The chosen trajectory contained a wealth of competing multi-disciplinary science opportunities (see Fig. 3).

Making the most of these opportunities presented challenges in allocating observing time to different disciplines and instruments, and in preserving the precise timing required when there can be a gap of years from science selection to execution. Fairly allocating observing time among the disciplines required intense advance planning, complicated by needing consensus among the various disciplines. To accommodate all of these concerns, the science planning process was segmented along science discipline lines[4]. After the release of the final trajectory, Science Planning divided the entire trajectory into smaller segments that were assigned to science discipline working groups. There are six discipline working groups, made up of science planning engineers, scientists from instrument teams, and interdisciplinary scientists. Each working group focuses on a different aspect of Cassini science: the Titan Orbiter Science Team (TOST) concentrates on Titan observations, the Satellite Orbiter Science Team (SOST) on observations of all other satellites, and the Saturn and Rings Target Working Teams (TWTs) are responsible for Saturn and the ring system, respectively. The Magnetosphere and Plasma Science (MAPS) TWT focuses on Saturn's magnetosphere, while the Cross Discipline TWT considers all science objectives during apoapse periods. Each TWT or OST's segments include opportunities especially of interest to that TWT or OST. For example, TOST segments generally run from a day before each Titan encounter closest approach to a day after.

The science observations contained in each discipline segment must be considered against one more metric. CSM funding levels will be significantly lower than prime and extended mission funding. Consequently, all CSM science is driven by a carefully honed set of prioritized science objectives. To establish these objectives, each discipline working group identified their top priority science objectives for the CSM. These objectives either *i)* addressed the goal of observing seasonal change in the Saturnian system, understanding underlying processes, and preparing for future missions, or *ii*) were new questions that arose out of prime and extended mission science (e.g. determining the composition and distribution of Titan's newly discovered lakes). The Project Scientist then constructed a matrix of CSM science objectives, and slotted them as Priority 1, 2, or 3. Each discipline working group must ensure that any observations planned for the CSM meet the Priority 1 objectives and as many Priority 2 and 3 objectives of the CSM as is possible within the observation time allotted to that discipline. Each working group is responsible for developing fully integrated timelines of the science that will be accomplished during their segments. Fully integrated segments are delivered to the Science Planning Team, which combines the segments into 10 week sequences that are uplinked to the spacecraft at the end of the implementation process. Each discipline developed its own method of getting from raw unintegrated segments to detailed designs ready to be included in a sequence. TOST's "jumpstart" method is detailed in the next section.

III. Why a Jumpstart?

During the first extended mission, TOST learned that the best way to achieve Cassini's Titan science goals was via a "jumpstart" process prior to final delivery of the trajectory. The jumpstart process was driven by two main objectives: the desire to increase Titan science by balancing across the entire set of flybys; and the desire to increase Titan science by influencing the flyby altitudes.

Looking at the entire set of 56 flybys and their associated science opportunities at once (instead of one-by-one) made it easier to work trades among different scientific objectives identified by the four Titan disciplines (Magnetospheric Interaction, Atmospheric, Surface, and Interior). This process also helps us achieve the best balance of Titan science across all the flybys. First, the instrument teams were asked to look at the entire set of opportunities and to prioritize which flybys best achieved their objectives. Next, the group was asked to decide on the best use of each flyby based on the instrument priorities. Finally, the interdiscipline leads were asked to assess the entire allocation for overall balance.

The jumpstart also allowed TOST to influence the final altitudes of the Titan flybys. The minimum safe altitude where it is safe for Cassini to fly through Titan's atmosphere depends on the pointing at closest approach. The pointing at closest approach depends on the type of science being done at closest approach. The Titan flyby altitudes are thus important for both tour navigation and Titan science. Altitude is a particularly critical parameter for INMS and in-situ sampling of Titan's atmosphere, where measurements at lower altitudes deeper in the atmosphere are always better from a science viewpoint. The flyby altitude is also important for the ORS suite of instruments, as a deeper flyby requires that the spacecraft use thrusters instead of reaction wheels to control attitude. The transition from wheels to thrusters (and vice-versa on the outbound leg) takes time, which reduces science opportunities. Thruster control is also less steady than reaction wheel control, which contributes to lower quality data. Hence, some instruments would prefer lower altitudes on their flybys, and other instruments would like to raise the altitude. The tour designers could change some flyby altitudes to give better science opportunities, but only if changes were requested within a very short window of opportunity after the initial tour was chosen and before the final trajectory was released. Via the jumpstart, allocating closest approach time fit within that narrow window, taking just over two months. Hence, TOST had enough time to give feedback to the mission designers on which flyby alitudes should be tweaked, and thus influence the final trajectory design.

The jumpstart is also an efficient use of our Titan scientists' time. Integrating flybys on a one-by-one basis as part of the usual TOST workload would mean that the scientists responsible for making high-level science trades would need to attend an every-two-weeks meeting that addresses both long range planning and detailed implementation issues. Key long-range-planning personnel are more likely to attend (and be fully engaged in) a few targeted meetings addressing major science objective achievement issues.

A final added jumpstart benefit, unique to the CSM, was finishing early development work prior to a major funding decrease. Early development of complete, conflict free master timelines , while the science and operations teams were still fully funded, decreased the future integration and implementation workload.

IV. The Jumpstart Process

The process of integrating Titan flybys starts when the PSG selects a brand-new tour, laying out the planned trajectory for a new mission phase. In addition to a detailed trajectory file, the tour release includes specifics on each flyby, including the altitude, latitude, longitude, groundtrack coverage and lighting phase. Solar and RSS occultation plots showing latitude for ingress and egress are also provided. Each instrument team uses these inputs to search for science opportunities that will meet the science objectives of the CSM. The key science objectives for Titan in the CSM include examining seasonal and temporal change, and answering new questions. Table 1 summarizes the prioritized Titan science objectives.

Table 1. Cassini Solstice Mission Prioritized Titan Science Objectives

		TITAN
SEASONAL-TEMPORAL CHANGE	Priority 1	**TC1a** - Determine seasonal changes in the methane-hydrocarbon hydrological cycle: of lakes, clouds, aerosols, and their seasonal transport.
		TC1b - Determine seasonal changes in the high-latitude atmosphere, specifically the temperature structure and formation and breakup of the winter polar vortex.
	Priority 2	**TC2a** - Observe Titan's plasma interaction as it goes from south to north of Saturn's solar-wind-warped magnetodisk from one solstice to the next.
NEW QUESTIONS	Priority 1	**TN1a** - Determine the types, composition, distribution, and ages, of surface units and materials, most notably lakes (i.e. filled vs. dry & depth; liquid vs. solid & composition; polar vs. other latitudes & lake basin origin).
		TN1b - Determine internal and crustal structure: Liquid mantle, crustal mass distribution, rotational state of the surface with time, intrinsic and/or internal induced magnetic field.
		TN1c - Measure aerosol and heavy molecule layers and properties.
	Priority 2	**TN2a** - Resolve current inconsistencies in atmospheric density measurements (critical to a future Flagship mission).
		TN2b - Determine icy shell topography and viscosity.
		TN2c - Determine the surface temperature distribution and cloud distribution.
		TN2d - Determine surface and tropospheric winds.

The entire Jumpstart process took over a year, starting with the CSM tour decision from three candidate tours at the January 2009 PSG Meeting; the first part (determining closest approach science) took only slightly more than two months. The jumpstart was a five stage process:

1. Team prioritization of initial inputs
2. Group discussion of each flyby and its best use
3. Determination of closest approach science (and therefore attitude) and the overall balance
4. Requesting tour tweaks
5. Templatizing out to the segment boundaries

A. Stage 1: Team prioriitization of initial inputs

The process began with an all-day meeting in February that started with an overview of the tour to set context, followed by brief presentations from each instrument team addressing prioritized science objectives and which flybys satisfy those objectives within the highly contested period of +/- 2 hours of each closest approach. Instrument teams indicated their level of priority in all flybys by assigning points for each flyby, using an Excel template. Each team was allowed two 10-point highest priority selections, "a few" 5-point high priorities, "more" 3-point medium priorities, and as many 1-point low priorities as desired (see Table 2). Teams were encouraged to include short comments with their prioritizations. The TOST Science Planners take the inputs and combine them into one master Excel spreadsheet showing each flyby, the flyby altitude, and the priority rankings for each team. This master spreadsheet gives immediate insight into which flybys are the most valuable to multiple disciplines.

Table 2. Sample of Instrument Flyby Priority Inputs

Flyby	Altitude (km)	ISS Points	VIMS Points	RADAR Points	NAV Points	RSS Points	CIRS Points	UVIS Points	INMS Points	CAPS Points	MAG Points	RPWS Points
134TI_T71	1005		1	5					10	1	10	1
138TI_T72	8124		5	1			5			3	0	1
140TI_T73	7921		1	1			3			3	3	1
145TI_T74	3640	3	3	1			5			5	0	1
147TI_T75	9996		1	0			3			10	5	10
148TI_T76	1862		5	3		3	1			5	5	1
149TI_T77	1383		5	3		5	1		5	1	1	1
153TI_T78	5941		3	1		5	10	5		5	5	10
158TI_T79	3763		3	1			5			10	0	1
159TI_T80	29331	10	1	0			3			0	0	0

B. Stage 2: Group discussion of each flyby and its best use

Over the next month, the full TOST group attended two extended telecons focused on the best scientific use for each flyby. A key strategy was to focus on the highest priority science objectives. Alternate opportunities for certain science objectives were identified. An attempt was made to give every instrument team their most important flybys. The group also identified new conflicts, solved old ones, and, where necessary, assigned homework to clarify issues. As had happened in the Prime and Equinox Missions, the flybys fell into "sets" which satisfied similar scientific objectives. One example is the set of flybys containing solar or earth occultations. The trajectories that create these occultation are similar, but the pointing required for a solar occultation is incompatible with that for an earth occultation – a choice must be made between the two. By considering all such obvious "sets", TOST could discuss and balance all the similar flybys at one time. There were operational concerns to consider, as well. For example, the spacecraft's available power decreases over time. This restricts the number of instruments that can operate at once, so using certain instruments later in the CSM means that other instruments must be put in sleep mode. The warmup requirements of some instruments are complex by themselves; if two such instruments were both allocated time during a flyby, the complexity would escalate, so some instruments cannot share flybys. In general, our goal was to simplify timelines wherever possible, to "integrate what we can implement" within the reduced funding profile of the CSM.

C. Stage 3: Determination of closest approach science

The next step in the jumpstart process was an in-person 3 day workshop, limited to one representative per instrument team, project interdisciplinary scientists (IDSs) for Titan, and the Science Planning TOST leads. The limited attendence represented a balance between fair representation and leanness. If the group is too large then the discussion slows too much. TOST was originally created as an open decision making group, but its members found that limiting the representation for the final key decision meeting to one per team was required to make significant progress. On the first day of the in-person workshop, each team presented their assessment of the draft allocation and pointed out where the allocation was weak in meeting the science objectives to which their instrument contributes. Then the IDSs presented their thoughts on the overall allocation and the remaining undecided flybys. The group as a whole reviewed the IDS recommendations and agreed upon a final allocation of the closest approach +/– 2 hours that was balanced among the four different Titan science disciplines (see Table 3[5]). One flyby was

Table 3. Final Science Allocations for all 56 Titan CSM flybys. Each flyby listing includes the pre-tweaked altitude at closest approach, the instruments that will be directing the spacecraft attitude during the period extending from –/+ 2 hours of closest approach, and the specific science emphasis for each flyby.

Flyby	Altitude (km)	Prime instruments	Science emphasis
T71	1005	CAPS, INMS, RADAR	Mid southern latitude dawn side pass
T72	8124	CIRS, VIMS, ISS	New surface territory, highest southern latitude
T73	7921	CAPS, CIRS	Composition, aerosols, thermal map
T74	3640	CAPS	Upstream pass
T75	9996	CAPS	Wake crossing
T76	1862	CIRS, VIMS	Belet sand sea
T77	1383	RADAR	Xanadu
T78	5941	CIRS, VIMS, UVIS, CAPS	Composition, aerosols, southern vortex, wake crossing
T79	3763	CAPS	Excellent upstream pass
T80	29331	ISS	Mid / high southern trailing hemisphere
T81	31172	ISS	High southern leading hemisphere and Ontario Lacus on terminator
T82	3844	CIRS	Composition, aerosols, thermal map
T83	990	INMS, RADAR	Northern lakes change detection
T84	990	RADAR, INMS	Global shape
T85	990	CIRS, VIMS	Northern lakes
T86	990	CIRS, INMS	Northern lakes
T87	990	INMS, NAV	Atmospheric density
T88	1164	CIRS, VIMS	Temperature at equator
T89	1500	RSS, CAPS	Gravity field, flank encounter
T90	1302	CIRS, VIMS	Tui Regio, Xanadu
T91	990	RADAR, CAPS	Global shape, altimetry, stereo of small northern lakes
T92	990	RADAR, INMS, VIMS	Stereo (with T91)
T93	990	ISS, VIMS	High northern leading latitudes, Ontario Lacus outbound
T94	990	VIMS, ISS, CIRS	High northern lakes composition
T95	990	ISS, RADAR, INMS	High northern lakes coverage
T96	990	ISS, VIMS, CIRS	High northern lakes, western Xanadu
T97	3087	VIMS, CIRS	Dunes
T98	2500	RADAR	Ontario Lacus change detection
T99	1612	RSS, CAPS	Gravity field
T100	990	CIRS, VIMS, INMS	Atmospheric structure
T101	2515	RSS	Occultation at high latitude for polar vortex, bistatic for surface properties
T102	3288	RSS	Occultation at high latitude for polar vortex, bistatic for surface properties
T103	4810	UVIS	Solar occultation at high latitude for polar vortex, stellar occ near equator
T104	990	INMS, RADAR, ISS	Southern edge of Kraken Mare
T105	990	VIMS, CIRS	Kraken Mare composition
T106	990	RSS	Bistatic for Kraken Mare properties
T107	990	INMS, NAV	Atmospheric density
T108	990	RADAR, INMS	Southern edge of Ligela
T109	1200	VIMS, CIRS	Punga Mare, Sinlap
T110	2270	VIMS, CIRS	Northern lakes composition
T111	2722	VIMS, CIRS	Xanadu
T112	10964	CIRS	Composition, aerosols, thermal map
T113	1036	MAG	Intrinsic magnetic field
T114	11907	ISS, CIRS	Hotei, Xanadu
T115	3830	CIRS	Composition, aerosols, thermal map
T116	990	UVIS, VIMS	Solar occultation
T117	990	RSS	Occultation for seasonal variation
T118	990	UVIS, INMS	Atmospheric density
T119	990	INMS, RSS	
T120	990	CIRS, RADAR, INMS	Small southern lakes, global shape
T121	990	VIMS, RADAR	Tui Regio, Hotei
T122	1679	RSS	Gravity field
T123	1766	VIMS, CIRS	Hotei

particularly important to two disciplines and the final decision on which instrument team would be allocated was deferred until January 2010. Once the final allocation of flybys was agreed upon, the third day of the meeting was used to fill in timelines for +/- 2 hours around closest approach for each flyby and to finish the list of tweaks that TOST would request be made to the CSM trajectory (see Table 4). A handoff package went to the Attitude and Articulation Control System (AACS) team for analysis.

Table 4. Sample of Attitude Tweak Requests submitted to the tour navigators

Priority	Tweak Request	Science Rationale
1	Substantially lower a second flyby – T113.	T70 was substantially lowered in the first extended mission in an attempt to measure an intrinsic magnetic field.
2	Lower as much as possible those flybys (15) for which INMS is collecting data with prime pointing at closest approach.	To improve the data set for atmospheric density by measuring deeper in the atmosphere).
3	Raise a subset of flybys (9) for which optical remote sensing is prime to an altitude that no longer requires thrusters (>1400km).	We were hopeful that the hydrazine savings would be appealing and that these had a good chance to get into the tweaked trajectory.

D. Stage 4: Requesting tour tweaks

With the proposed tweaks in hand and the AACS health and safety analysis, the mission planners assessed the impact of the proposed Titan flyby altitude changes. Their results were presented in May, allowing the tour designers to create the final trajectory for approval by the complete PSG.

E. Stage 5: Templatizing out to the segment boundaries

With the difficult work of timelines for the closest approach period completed, TOST moved on to expand the flyby detailed timelines to the segment boundaries. TOST simplifies this process via integration templates (Fig. 4). Depending solely on the observation time relative to closest approach, and if Titan's visible hemisphere is illuminated or unilluminated, TOST scientists can select an instrument and immediately "plug in" a pre-integrated timeline. One set of about 12 templates covers the period extending from –5 to –2 hours prior to closest approach on the inbound leg, and also +2 to +5 hours after closest approach. The 5 to 9 hour period has about 8 templates, the 9 to 13 hour period has ~4, and the 13 to 24 hour period has two. The tempates were created from letting the TOST team integrate the first 20 flyby without any restrictions and then determining that there was, in fact a pattern (or subset) to the choices. The original set of templates was simply each "type" of observation we had done broken down by range.

As with the closest approach time allocations, integrating out to the segment boundaries attempts to balance science across the entire set of 56 flybys. Additional operational constraints come into play. One crucial factor is availability of a good "waypoint": a spacecraft attitude that is the assumed starting and ending point for all observations. This attitude needs to be "safe" for the entire time that it is used as a waypoint, causing no flight rule violations such as exposing instrument boresights to the Sun. Finding waypoints that are safe and which also keep a desired body vector towards Titan to reduce turn times can be difficult. If the only good waypoints during a flyby are with the ORS boresights pointing towards Earth, then ORS instruments might want to choose another flyby for their observations. Another constraint is the amount of data that can be downlinked at the end of the flyby. This depends on which DSN stations are available, and what data rates they will be able to support from Cassini. If downlink capacity is low, high data volume users such as an intensive MAPS campaign may opt for another flyby.

At the conclusion of the process, TOST has a package of master timelines (see e.g. Fig. 5) assigning observing and turn time for every TOST segment. The package is put on the shelf in this state until several months before the segment will be needed for sequence development.

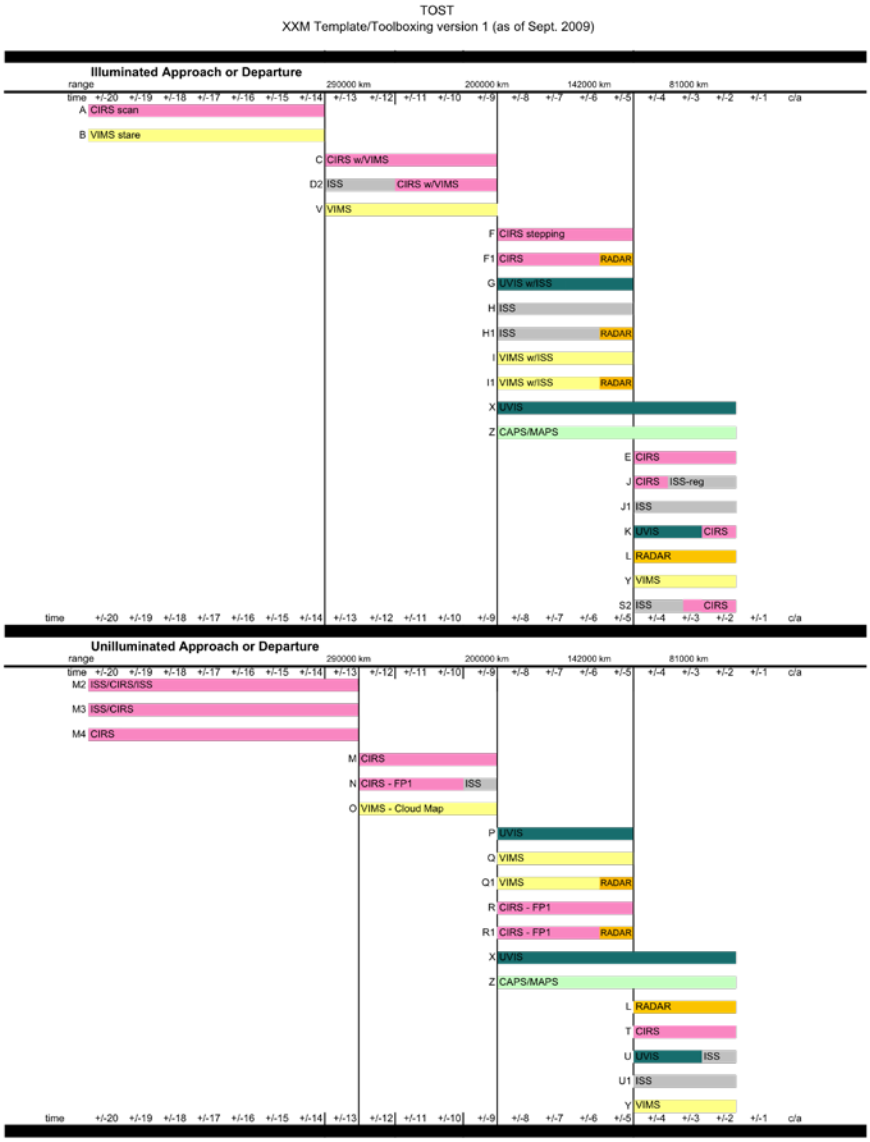

Figure 4. Titan Integration Templates. The top set of templates are for use during illuminated periods; the bottom set for unilluminated periods. Each template shows what instrument (and in some cases what field of view) chooses the spacecraft attitude. Templates can be used symmetrically with respect to closest approach; for example, Template R can be used from -09:00 to -05:00 on an unilluminated inbound leg,, or from +05:00 to +09:00 on an unilluminated outbound leg.

V. Conclusion

The CSM TOST jumpstart successfully allocated all of the Titan flyby closest approach periods among the 12 science instrument teams, including agreement on what science would be accomplished during each flyby. By looking at all 56 flybys at once, the best balance of interior, surface, atmospheric, and magnetospheric interaction science was achieved. By deciding on the closest approach attitudes early, it was possible to influence the final trajectory production and change some flyby altitudes to improve scientific return. In less than 15 hours of telecon time, integrated conflict-free timelines were completed for each Titan flyby detailing allocation of the time outside closest approach using re-useable templates. By completing the jumpstart during the equinox mission which is funded at the same level as the prime mission, the TOST team was able to take advantage of full participation by key long-range-planning personnel who might not be able to attend as many meetings during the CSM due to the lower funding profile. This process allowed the Cassini mission to maximize Titan science return across the CSM.

138TI_T72	8175	Lit Outbound				
Start Time	**End Time**	**Prime Activity**	**Obs. Detail**	**Op Mode**	**TLM Mode**	**Comments**
2010-267T05:17:00	2010-267T05:57:00	SP Turn to WP				
2010-267T05:57:00	C/A - 12:26:00	OD Uncertainty Dead Time				
C/A -12:26:00	-09:00	CIRS	N			
-09:00	-05:00	CIRS	R			
-05:00	-02:15	CIRS	T			
begin custom period						
-02:15	**-00:15**	**CIRS**	**CIRS will turn to VIMS attitude**			FIRLMB at 87S and 60N; FIRLMBAER and INT
-00:15	**0**	**VIMS**				
2010-267T18:38:41		**CLOSEST APPROACH**	**NEG_Y to Titan,**			
0	**+02:15**	**VIMS**				NT2 5km/pixel equat
end custom period						
+02:15	+05:00	UVIS	X			
+05:00	+09:00	UVIS	X			
+09:00	+14:00	VIMS	V ISS riding along			
+14:00	+22:28	VIMS	B ISS riding along			
C/A + 22:28:19	**2010-268T17:22:00**	OD Uncertainty Dead Time				
2010-268T:17:22:00	**2010-268T18:02:00**	SP Turn to Earth for downlink				
2010-268T18:02:00	2010-268T19:32:00	Y-Bias window				
2010-268T19:32:00	**2010-269T06:17:00**	Canberra 70M Array		DFPW Normal		

Figure 5. Example of completed master timeline for a Titan flyby. This master timeline for T72 gives a time ordered listing of which team controls the spacecraft attitude at every point in the flyby period. Times are given in absolute spacecraft time or in flyby closest-approach epoch-relative time. Templates are noted under observation details. Operational modes and telemetry modes are not completed until detailed integration immediately prior to sequence development.

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