CASSINI

SATURN ARRIVAL MISSION DESCRIPTION

JUNE 2004

Jet Propulsion Laboratory
California Institute of Technology

PD 699-100, Rev O (supplement)
JPL D-5564, Rev O (supplement)
1.0 SATURN APPROACH

Cassini arrives at Saturn in the early evening hours of June 30, 2004 (Pacific time; on July 1, 2004 UTC). Near closest approach to Saturn, Cassini performs a 96-minute burn to enter Saturn orbit, the culmination of several decades of development and 6.7 years of cruise to reach its final destination.

During the last few weeks of approach to Saturn, three significant events occur. First, Trajectory Correction Maneuver #20 (TCM-20) is performed 34 days before arrival to place the spacecraft on the proper trajectory to encounter Saturn’s outermost major satellite, Phoebe, 15 days later. Second, the spacecraft passes by Phoebe at an altitude of only 2,000 km; and the final approach maneuver, TCM-21 is executed.

Other than maneuvers and the Phoebe encounter, the spacecraft is engaged in daily science observations of Saturn, its satellites, magnetospheric and particle environment, optical navigation image collection, and playback of science and engineering data.

1.1 TCM-20

TCM-20 is a significant maneuver at 35 m/s (6 minutes), and to prepare for Saturn Orbit Insertion (SOI), the maneuver has been designed to completely checkout the spacecraft engineering systems prior to SOI. TCM-20 is a pressurized burn which exercises all of the hardware to be used during SOI, including the regulator, high pressure latch valves, and main engine. Latch valves 10, 20, and 30 are opened and pyro valve 25 is fired to pressurize the bipropellant system before the maneuver. There is a backup window the following day if circumstances prevent execution of TCM-20 during the prime pass. Navigation analyses have shown that this maneuver can be delayed for up to 3 days with reasonably low propellant costs.

In addition to pressurizing the biprop system, High Gain Antenna (HGA) communication is suspended and Low Gain Antenna 2 (LGA-2) is enabled to allow Earth to monitor Cassini’s progress during the burn (via the Goldstone tracking station) as closely as possible. This scenario is very similar to the comm link for SOI and will be used to test the ground operations for insertion.

1.2 PHOEBE ENCOUNTER

The first targeted flyby of the tour (though it occurs before SOI) is with Phoebe 19 days prior to the SOI burn. The arrival date and trajectory to Saturn was specifically selected to accommodate this flyby and is the only opportunity during the mission to study Phoebe at close range. Phoebe’s orbit is simply too far from Saturn – at almost 13 million kilometers, nearly four times as far as the next closest major satellite Iapetus – to make a later encounter feasible. At closest approach, Cassini will pass a mere 2,000 km from the surface of Phoebe, offering resolution of up to 15 meters per pixel. This distance is close enough to get very high resolution imagery, fields and gravitational studies of the body but is also far enough away to avoid any dangerous debris which might be in the satellites’ vicinity. This flyby will provide far more information about Phoebe than the distant observations made by Voyager, which imaged the satellite at only a few pixels across. Cassini’s flyby will help to determine surface properties, geological history, surface age, body shape, local topography, and the distribution of surface materials. Multi-color mapping of almost the entire surface at 0.3 to 2.1 km/pixel is planned.

Phoebe was discovered by William Henry Pickering in 1898 and has a rotation period of about 9.4 hours, an orbital period of 550 days, and a diameter of about 220 km. Among planetary satellites, Saturn’s outermost satellite is arguably the most unusual. Its inclined, retrograde, chaotic orbit is strong evidence that the moon is a captured object. Phoebe is
**SOI ACTIVITIES TIMELINE**

**LARGE SCALE**

**Encounters**
- Phoebe Flyby
  - 2000 km @ 6.4 km/s
  - SOI-19 d
- Saturn Periapsis T0 Flyby
  - 1.3 Rs 339,000 km @ 8.3 km/s
  - SOI+1d

**Maneuvers**
- TCM 20
  - Phoebe Targeting
  - Bi-prop pressurization
  - SOI-34d
- TCM 21
  - SOI targeting
  - SOI-14d
- TCM 22
  - contingency
  - SOI-9d
- SOI
- OTM-001
  - SOI cleanup
  - SOI+3d
- OTM-001A
  - SOI cleanup 2 (if needed)
  - SOI+17d

**Activities**
- Daily science observations & playback
- Quiet Period 7 days
- Critical Sequence
- Solar Conjunction

**Sequence**
- S1
- S2

**Day of Year (DOY)**
- 145 150 155 160 165 170 175 180 185 190 195 200

**Month**
- May
- June
- July
<table>
<thead>
<tr>
<th>Orbiter UTC</th>
<th>Ground UTC</th>
<th>Pacific Time</th>
<th>Time wrt SOI</th>
<th>Activity Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>135T18:40</td>
<td>May 14 20:00</td>
<td>Fri May 14 01:00 PM</td>
<td>SOI-47d07h</td>
<td>First tour sequence (S01) begins 36-day sequence includes Phoebe targeting maneuver, Phoebe flyby, and SOI targeting maneuver</td>
</tr>
<tr>
<td>143T16:53</td>
<td>May 22 18:14</td>
<td>Sat May 22 11:14 AM</td>
<td>SOI-39d08h</td>
<td>Main engine cover opens Cover protecting main engine nozzles opens (retracts) for upcoming approach maneuver</td>
</tr>
<tr>
<td>145T19:34</td>
<td>May 24 20:55</td>
<td>Mon May 24 01:55 PM</td>
<td>SOI-37d06h</td>
<td>Open low pressure biprop valves Prepare for upcoming maneuver by opening latch valves 20, 30</td>
</tr>
<tr>
<td>146T19:29</td>
<td>May 25 20:50</td>
<td>Tue May 25 01:50 PM</td>
<td>SOI-36d06h</td>
<td>Un-isolate oxidizer side of biprop system Prepare for upcoming maneuver by firing pyro 25</td>
</tr>
<tr>
<td>148T22:22</td>
<td>May 27 23:43</td>
<td>Thu May 27 04:43 AM</td>
<td>SOI-34d03h</td>
<td>Final pressurization of biprop system Open latch valve 10 two minutes before burn TCM-20 burn start</td>
</tr>
<tr>
<td>148T22:24</td>
<td>May 27 23:45</td>
<td>Thu May 27 04:45 AM</td>
<td>SOI-34d03h</td>
<td>Phoebe targeting maneuver burn start Trajectory Correction Maneuver (TCM) 20; main engine maneuver, velocity change = 35 m/s (78 mph); 6 minute burn</td>
</tr>
<tr>
<td>163T19:33</td>
<td>Jun 11 20:56</td>
<td>Fri Jun 11 01:56 PM</td>
<td>SOI-19d06h</td>
<td>Phoebe flyby closest approach Altitude = 2,000 km (1,240 miles), speed = 6.35 km/s (14,200 mph), phase angle = 25 deg</td>
</tr>
<tr>
<td>164T12:05</td>
<td>Jun 12 13:28</td>
<td>Sat Jun 12 06:28 AM</td>
<td>SOI-18d13h</td>
<td>Load SOI critical sequence into RAM Critical sequence is copied from the Solid State Recorders (SSRs) into spacecraft memory</td>
</tr>
<tr>
<td>165T07:52</td>
<td>Jun 13 09:15</td>
<td>Sun Jun 13 02:15 AM</td>
<td>SOI-17d17h</td>
<td>Saturn Orbit Insertion (SOI) targeting maneuver burn start TCM-21; main engine maneuver, velocity change = 7 m/s (16 mph), 1 minute burn</td>
</tr>
<tr>
<td>171T21:52</td>
<td>Jun 19 23:15</td>
<td>Sat Jun 19 04:15 PM</td>
<td>SOI-11d03h</td>
<td>Second tour sequence (S02) begins 41-day sequence includes SOI, T0 flyby, SOI cleanup maneuver, and Solar Conjunction</td>
</tr>
<tr>
<td>173T20:52</td>
<td>Jun 21 22:15</td>
<td>Mon Jun 21 03:15 PM</td>
<td>SOI-09d04h</td>
<td>SOI contingency maneuver TCM-22; placeholder for contingencies; not expected to be used</td>
</tr>
<tr>
<td>174T00:00</td>
<td>Jun 22 22:23</td>
<td>Tue Jun 22 02:23 AM</td>
<td>SOI-08d05h</td>
<td>Transition to thruster control Reaction wheels are turned off and thrusters are enabled through end of SOI</td>
</tr>
<tr>
<td>175T00:00</td>
<td>Jun 23 01:23</td>
<td>Tue Jun 23 03:23 AM</td>
<td>SOI-08d01h</td>
<td>Activate SOI critical sequence and begin quiet period 8-day period of minimal spacecraft activity begins; Solid State Recorders (SSRs) set to SOI configuration</td>
</tr>
<tr>
<td>183T01:12</td>
<td>Jul 01 02:36</td>
<td>Wed Jun 30 07:36 PM</td>
<td>SOI-00h00m</td>
<td>Saturn Orbit Insertion Main engine maneuver, velocity change = 626 m/s (1400 mph); 96 minute burn</td>
</tr>
<tr>
<td>183T03:07</td>
<td>Jul 01 04:31</td>
<td>Wed Jun 30 09:31 PM</td>
<td>SOI+01h55m</td>
<td>SOI complete; turn off Earth-line for post-burn science observations Background sequence turns spacecraft to view rings and magnetosphere</td>
</tr>
<tr>
<td>183T05:36</td>
<td>Jul 01 07:00</td>
<td>Thu Jul 01 12:00 AM</td>
<td>SOI+04h24m</td>
<td>Spacecraft returns to Earth-point; SOI data playback begins Double playback of SOI science &amp; engineering data for 19.5 hours; data played back over Madrid, then Goldstone</td>
</tr>
<tr>
<td>184T09:30</td>
<td>Jul 02 10:54</td>
<td>Fri Jul 02 03:54 AM</td>
<td>SOI+01d08h</td>
<td>Closest approach to Titan Distance = 339,000 km (205,000 miles), phase angle = 67 deg</td>
</tr>
<tr>
<td>184T17:51</td>
<td>Jul 02 19:15</td>
<td>Fri Jul 02 12:15 AM</td>
<td>SOI+01d17h</td>
<td>Titan playback starts Playback of Titan-0 closest approach data</td>
</tr>
<tr>
<td>185T20:06</td>
<td>Jul 03 21:30</td>
<td>Sat Jul 03 03:30 PM</td>
<td>SOI+02d19h</td>
<td>SOI cleanup maneuver burn start Orbital Trim Maneuver (OTM) 001, velocity change = 5 m/s (11 mph)</td>
</tr>
<tr>
<td>187T04:20</td>
<td>Jul 05 05:44</td>
<td>Sun Jul 04 10:44 AM</td>
<td>SOI+04d03h</td>
<td>Solar conjunction begins Cassini is passing behind Sun as seen from Earth; Sun-Earth-Cassini angle = 3° (decreasing)</td>
</tr>
<tr>
<td>188T10:12</td>
<td>Jul 06 11:36</td>
<td>Tue Jul 06 04:36 AM</td>
<td>SOI+05d09h</td>
<td>Solar conjunction Sun-Earth-Cassini angle = 2° (decreasing); no commanding or playback possible</td>
</tr>
<tr>
<td>193T07:11</td>
<td>Jul 11 08:35</td>
<td>Sun Jul 11 01:35 AM</td>
<td>SOI+10d06h</td>
<td>Solar conjunction Sun-Earth-Cassini angle = 2° (increasing); commanding and playback resumes</td>
</tr>
<tr>
<td>194T12:51</td>
<td>Jul 12 14:15</td>
<td>Mon Jul 12 07:15 AM</td>
<td>SOI+11d12h</td>
<td>Solar conjunction ends Cassini emerges from behind Sun as seen from Earth; Sun-Earth-Cassini angle = 3°</td>
</tr>
<tr>
<td>199T13:21</td>
<td>Jul 17 14:45</td>
<td>Sat Jul 17 07:45 AM</td>
<td>SOI+16d12h</td>
<td>Post-conjunction SOI cleanup maneuver burn start OTM-001A, velocity change = 1 m/s (2 mph)</td>
</tr>
<tr>
<td>212T21:32</td>
<td>Jul 30 22:55</td>
<td>Fri Jul 30 03:55 PM</td>
<td>SOI+29d20h</td>
<td>End of background sequence Next tour sequence S03 begins</td>
</tr>
</tbody>
</table>
one of only two of the nine large satellites of Saturn which is not tidally locked to Saturn (the other is Hyperion). It has an incredibly dark surface which reflects only 6% of the light falling upon it. Some suspect that it may be the source of the dark material which covers the leading face of Iapetus. Spectrally, Phoebe shows the presence of water ice, but also reveals a surface composition similar to C-type asteroids (carbonaceous chondrites).

Determining whether or not Phoebe is asteroidal in character is an important scientific goal. Geologic, morphologic and compositional evidence should also point to the origin of Phoebe: the Kuiper belt, a Centaur or even the main asteroid belt. Another key measurement is the density of Phoebe from radio science tracking and imaging data (for volume). This will help determine if it is a highly porous 'rubble pile', or a more compact body as might be suggested from its roughly spherical shape. The density value will also used to constrain its composition and indicate the rough proportions of rock and ice in its make-up.

VIMS will obtain the first ever resolved spectra of the surface of Phoebe, up to 0.5 km/pixel at closest approach, with full range 0.4 to 5-micron spectra. This data will be used to derive compositional maps of Phoebe’s surface.

Phoebe is an exceptionally interesting target for CIRS, due to its unusual surface composition compared to most of the icy satellites, and its warm temperatures which will provide high S/N data. CIRS plans global mapping of composition and both day and night temperature distributions.

UVIS will measure Phoebe’s ultraviolet surface reflectance, providing the first ultraviolet albedo map of this interesting body (more similar to an asteroid than to the other icy moons of Saturn). The UVIS measurements will aid in understanding Phoebe’s compositional makeup and distribution of volatiles.

RADAR observations of Phoebe will penetrate to between 2 cm and 20 cm, and will constrain the bulk density and/or the relative ice cleanliness in the upper layer of regolith.

RPWS will look for evidence of a Phoebe - Solar Wind interaction.

Around Phoebe closest approach the Cassini spacecraft may cross the Hill sphere of this icy moon. Particles detected inside the Hill sphere most likely originate from the surface of the moon. CDA measurements starting at closest approach will provide important information about the elemental composition of the moon surface as well as about the dust production mechanism itself.

The Phoebe flyby will be the first use of the “live update” capability, where the pointing profile is updated in-flight after the sequence is already on board the spacecraft. The science operating modes used for this flyby will be 1) the ORS mode to allow ISS, CIRS, UVIS, and VIMS observations as well as a more accurate determination of the Phoebe rotation period and 2) the RSS2/RWA mode to allow mass determination. The closest approach at Phoebe occurs on 11 June, 2004, 19 days before SOI at 19:33 spacecraft time (1:56 pm Pacific time) at a speed of 6.35 km/s and phase angle of 25 degrees.

1.3 TCM-21

Five days after the Phoebe flyby, the last planned cruise maneuver, TCM-21, is performed to place the spacecraft on the precise trajectory for orbit insertion and the ring plane crossings before and after arrival. This 7 m/s burn is expected to take about 1 minute. This maneuver is conducted two weeks before arrival to ensure that a comfortable period of time exists to diagnose and work any unexpected problems (based on past project experience).
Cassini Phoebe Flyby
June 11, 2004 (DOY 163)

Closest approach
19:33 spacecraft time / 20:56 UTC / 1:56 pm Pacific Time
Altitude = 2,000 km (1,240 miles)
Phase = 25 deg

Plus one hour
Altitude = 22,870 km (14,210 miles)
Phase = 88 deg

Minus one hour
Altitude = 22,840 km (14,190 miles)
Phase = 82 deg
There is a final approach TCM opportunity at 10 days before arrival for a contingency maneuver, should one be required for final SOI targeting. The project does not expect to use this maneuver.

2.0 SATURN ORBIT INSERTION (SOI)

Saturn Orbit Insertion occurs on June 30, 2004 Pacific time (July 1 UTC). In addition to the Phoebe flyby, this arrival date also allows an opportunity for a non-targeted flyby of Titan about 31 hours after SOI at a distance of less than 340,000 km. This Titan-0 opportunity (revolution 0 is defined as the orbit segment from SOI until the initial apoapsis) may be used to confirm the Titan wind direction prior to the Probe delivery.

2.1 SOI SCIENCE ACTIVITIES

The SOI time period represents the closest flyby to Saturn of the Cassini orbital tour and, therefore, provides a unique opportunity to study the planet and rings from extremely close range. Cassini passes a mere 20,000 km above the cloud tops of the planet (closer than any other spacecraft in history) and only 15,000 km above Saturn’s main rings, more than ten times closer to the rings than at any other point in the mission, and in a region where observations have never before been taken.

Merely being so close to the planet allows Cassini’s Magnetometer to measure the strength and direction of the magnetic field. Small irregularities in the field so close to the planet can tell us about the structure of the very deep interior and core of Saturn, and help us understand how magnetic fields are generated. The close flyby of Saturn also provides an excellent opportunity to find the location of lightning in the atmosphere based on radio emissions emitted by the lightning strikes, and characterize the unique plasma environment near the rings.

The SOI period also includes two ring plane crossings close to the main ring system; Cassini’s advanced Radio and Plasma Wave Spectrometer is sensitive to dust particles impacting the spacecraft and these crossings can provide a record of the flux of dust particles as the spacecraft flies through the ring plane. These observations can tell us the density of micron-sized particles in the ring plane as well as the thickness of the dusty region.

Though the SOI burn would be most efficient if centered at closest approach to the planet, the project instead chose to end the burn near periapsis to allow for post-burn unique observations. Shortly after the burn is complete, the orbiter remote sensing instruments (Imaging Science Subsystem, Visual and Infrared Mapping Spectrometer, Composite Infrared Spectrometer, and Ultraviolet Spectrometer) all take data as fast as possible, with the spacecraft oriented in two different directions - not looking straight down, but instead covering as much of the rings as possible in the time available while simultaneously allowing the magnetic fields to be measured. Because ring properties are known to vary on very fine scales, and for unknown reasons, being able to resolve fine scale structure is essential to all Cassini’s remote sensing instruments, each of which can measure different properties of the rings (composition, temperature, and localized clumpy structure). Even finding a mutually satisfactory orientation to address both the magnetic field and remote sensing goals simultaneously, while avoiding harmful constraint violations, is a challenge. While this is all going on, the Radio and Plasma Wave Spectrometer continues to listen for radio wave evidence for lightning from the planet, waves in the ionosphere, and large meteoroid impacts on the rings.
After about 45 minutes of these observations, the spacecraft reorients to allow the very sparse neutral molecules in the atmosphere of the rings to be sniffed briefly - for about 5 minutes - by Cassini's Mass Spectrometer. These measurements will be combined with the continuously recorded measurements of the charged molecules by the Advanced Plasma Spectrometer to get a never-before available picture of how the rings exchange material with the planet. Then, after about an hour of this intense sampling of a never-before traversed region, the spacecraft is reoriented into a safe position for the outbound ring plane crossing. After traversing the ring plane, Cassini has time for a quick glimpse back at the sunlit face of the rings before turning to Earth to transmit all these unique data (twice, to be sure it is not lost in transmission).

2.2 SOI SEQUENCE OF EVENTS

The nominal (background) sequence which contains the SOI time period (but not the critical command events for orbit insertion) is called S02 and begins on June 19, 8 days after the Phoebe flyby and 11 days before SOI. The Critical Sequence which contains the critical command events is loaded to the Solid State Recorders 4 weeks before SOI, and loaded into the spacecraft RAM about 18 days before the burn.

The spacecraft conducts normal science observations and daily playbacks until 8 days before arrival, when the spacecraft turns to Earth-point for a Quiet Period leading up to the SOI activities. The spacecraft transitions to thruster control at this point and is tracked continuously until shortly before the burn. During the Quiet Period and burn itself, only fields, particles and waves instruments will be on (CAPS, CDA, MAG, MIMI, and RPWS); other instruments will be either in sleep or off to maintain appropriate power margins for the critical burn event.

The purpose of the Quiet Period is to have the spacecraft in a quiescent state that minimizes the chance for a spacecraft anomaly prior to the SOI burn. No turns, instrument articulations or power state changes which are not directly related to orbit insertion are allowed. After the critical sequence is completed, the stringent SOI power restrictions are lifted.

<table>
<thead>
<tr>
<th>Instrument</th>
<th>On Power W</th>
<th>Sleep Power W</th>
<th>Off Power W</th>
<th>Quiet Period/Burn State</th>
<th>Quiet Period/Burn Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAPS</td>
<td>21.0</td>
<td>15.8</td>
<td>16.5</td>
<td>On</td>
<td>21.0</td>
</tr>
<tr>
<td>CDA (no art.)</td>
<td>11.7</td>
<td>12.0</td>
<td>11.25</td>
<td>On</td>
<td>11.7</td>
</tr>
<tr>
<td>CIRS</td>
<td>46.0</td>
<td>29.0</td>
<td>9.8</td>
<td>Sleep</td>
<td>29.0</td>
</tr>
<tr>
<td>INMS</td>
<td>26.6</td>
<td>16.6</td>
<td>4.0</td>
<td>Off</td>
<td>4.0</td>
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<tr>
<td>ISS NAC</td>
<td>26.2</td>
<td>22.3</td>
<td>9.0</td>
<td>Sleep</td>
<td>22.3</td>
</tr>
<tr>
<td>ISS WAC</td>
<td>19.4</td>
<td>16.4</td>
<td>5.0</td>
<td>Sleep</td>
<td>16.4</td>
</tr>
<tr>
<td>MAG</td>
<td>13.4</td>
<td>10.0</td>
<td>3.4</td>
<td>On</td>
<td>13.4</td>
</tr>
<tr>
<td>MIMI</td>
<td>25.9</td>
<td>16.9</td>
<td>2.3</td>
<td>On</td>
<td>25.9</td>
</tr>
<tr>
<td>RADAR</td>
<td>85.3</td>
<td>0.0</td>
<td>0.0</td>
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<td>0.0</td>
</tr>
<tr>
<td>RPWS</td>
<td>16.9</td>
<td>3.15</td>
<td>0.0</td>
<td>On</td>
<td>16.9</td>
</tr>
<tr>
<td>RSS</td>
<td>83.0</td>
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<td>0.0</td>
<td>Off</td>
<td>0.0</td>
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<tr>
<td>SCAS</td>
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<td>0.0</td>
<td>0.0</td>
<td>Off</td>
<td>0.0</td>
</tr>
<tr>
<td>UVIS</td>
<td>13.0</td>
<td>6.6</td>
<td>3.5</td>
<td>Sleep</td>
<td>6.6</td>
</tr>
<tr>
<td>VIMS</td>
<td>27.3</td>
<td>12.9</td>
<td>7.6</td>
<td>Sleep</td>
<td>12.9</td>
</tr>
<tr>
<td>Probe</td>
<td>0.0</td>
<td></td>
<td></td>
<td></td>
<td>0.0</td>
</tr>
</tbody>
</table>

Total 180.1
Available 186.6
SOI ACTIVITIES TIMELINE
SMALL SCALE, SPACECRAFT UTC

Geometry

Communications

Activities

Tracking

Spacecraft Time

UTC

Pacific Time

Hour of Day for DOY 182-183 (30 Jun - 01 Jul 2004)

SOI ACTIVITIES TIMELINE
SMALL SCALE, SPACECRAFT UTC

Geometry

Communications

Activities

Tracking

Spacecraft Time

UTC

Pacific Time

Hour of Day for DOY 182-183 (30 Jun - 01 Jul 2004)
<table>
<thead>
<tr>
<th>Orbiter UTC</th>
<th>Ground UTC</th>
<th>Pacific Time</th>
<th>Time wrt SOI</th>
<th>Activity</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>183T00:47</td>
<td>Jul 01 02:11</td>
<td>Wed Jun 30 07:11</td>
<td>SOI-00h25m</td>
<td>Ascending ring-plane crossing</td>
<td>Distance = 158,500 km (98,500 miles); High-Gain Antenna (HGA) is oriented to dust ram direction</td>
</tr>
<tr>
<td>183T00:57</td>
<td>Jul 01 02:21</td>
<td>Wed Jun 30 07:21</td>
<td>SOI-00h15m</td>
<td>Turn to burn attitude</td>
<td>Turn takes 10 min; 6 min spare time after turn completion before SOI end</td>
</tr>
<tr>
<td>183T01:11</td>
<td>Jul 01 02:35</td>
<td>Wed Jun 30 07:35</td>
<td>SOI-00h01m</td>
<td>Open latch valves</td>
<td>Valves opened in preparation for pressurized burn</td>
</tr>
<tr>
<td>183T01:12</td>
<td>Jul 01 02:36</td>
<td>Wed Jun 30 07:36</td>
<td>SOI-00h00m</td>
<td>Saturn Orbit Insertion burn start</td>
<td>Main engine maneuver, velocity change = 662 m/s (1400 mph); 96 minute burn</td>
</tr>
<tr>
<td>183T01:35</td>
<td>Jul 01 02:59</td>
<td>Wed Jun 30 07:59</td>
<td>SOI-00h23m</td>
<td>Cassini passes behind Saturn's F ring as seen from Earth</td>
<td>Communication still likely</td>
</tr>
<tr>
<td>183T01:42</td>
<td>Jul 01 03:06</td>
<td>Wed Jun 30 08:06</td>
<td>SOI-00h30m</td>
<td>Cassini passes behind Saturn's A ring as seen from Earth</td>
<td>Communication unlikely for 25 minutes</td>
</tr>
<tr>
<td>183T02:07</td>
<td>Jul 01 03:31</td>
<td>Wed Jun 30 08:31</td>
<td>SOI-00h55m</td>
<td>Cassini passes behind Cassini division as seen from Earth</td>
<td>Brief communication possible for 6 minutes</td>
</tr>
<tr>
<td>183T02:13</td>
<td>Jul 01 03:37</td>
<td>Wed Jun 30 08:37</td>
<td>SOI-01h01m</td>
<td>Cassini passes behind Saturn's B ring as seen from Earth</td>
<td>Communication unlikely for 28 minutes</td>
</tr>
<tr>
<td>183T02:30</td>
<td>Jul 01 03:54</td>
<td>Wed Jun 30 08:54</td>
<td>SOI-01h18m</td>
<td>Saturn orbit achieved</td>
<td>Spacecraft has slowed enough to be captured by Saturn's gravity and is no longer in escaping orbit (78 min into burn)</td>
</tr>
<tr>
<td>183T02:39</td>
<td>Jul 01 04:03</td>
<td>Wed Jun 30 09:03</td>
<td>SOI-01h27m</td>
<td>Closest approach to Saturn in entire mission</td>
<td>Distance = 80,230 km (49,850 miles) from center of Saturn, 19,980 km (12,400 miles) from cloud tops</td>
</tr>
<tr>
<td>183T02:41</td>
<td>Jul 01 04:05</td>
<td>Wed Jun 30 09:05</td>
<td>SOI-01h29m</td>
<td>Cassini passes behind Saturn's C ring as seen from Earth</td>
<td>Communication restored until science turns (C ring is less opaque to Cassini radio freqs than A or B ring)</td>
</tr>
<tr>
<td>183T02:48</td>
<td>Jul 01 04:12</td>
<td>Wed Jun 30 09:12</td>
<td>SOI-01h36m</td>
<td>Saturn Orbit Insertion nominal burn end</td>
<td>Main engine cover is closed to protect engine nozzles during descending ring-plane crossing; will shift if burn ends late</td>
</tr>
<tr>
<td>183T02:51</td>
<td>Jul 01 04:15</td>
<td>Wed Jun 30 09:15</td>
<td>SOI-01h39m</td>
<td>Reconfigure radio comm, close main engine cover, begin turn to Earth-point</td>
<td>Will shift if burn ends late</td>
</tr>
<tr>
<td>183T02:54</td>
<td>Jul 01 04:18</td>
<td>Wed Jun 30 09:18</td>
<td>SOI-01h42m</td>
<td>Spacecraft on Earth-point</td>
<td>Will shift if burn ends late</td>
</tr>
<tr>
<td>183T02:57</td>
<td>Jul 01 04:21</td>
<td>Wed Jun 30 09:21</td>
<td>SOI-01h45m</td>
<td>Nominal end of critical sequence; main engine cover fully closed</td>
<td>Will shift if burn ends late</td>
</tr>
<tr>
<td>183T03:01</td>
<td>Jul 01 04:24</td>
<td>Wed Jun 30 09:24</td>
<td>SOI-01h48m</td>
<td>Cassini passes behind Saturn's D ring as seen from Earth</td>
<td>Communication remains likely (D ring is less opaque to Cassini radio frequencies than A or B ring)</td>
</tr>
<tr>
<td>183T03:06</td>
<td>Jul 01 04:30</td>
<td>Wed Jun 30 09:30</td>
<td>SOI-01h54m</td>
<td>Cassini should be in science attitudes and will not be communicating with Earth; otherwise communication possible</td>
<td>Background sequence takes over spacecraft control</td>
</tr>
<tr>
<td>183T03:07</td>
<td>Jul 01 04:31</td>
<td>Wed Jun 30 09:31</td>
<td>SOI-01h55m</td>
<td>Cassini should be in science attitudes and will not be communicating with Earth; otherwise communication not possible</td>
<td>Ion &amp; Neutral Mass Spectrometer (INMS) cover is removed for post-SOI observations</td>
</tr>
<tr>
<td>183T03:15</td>
<td>Jul 01 04:39</td>
<td>Wed Jun 30 09:39</td>
<td>SOI-02h03m</td>
<td>Jettison INMS cover</td>
<td>Cassini should be in science attitudes and will not be communicating with Earth; otherwise communication not possible</td>
</tr>
<tr>
<td>183T03:30</td>
<td>Jul 01 04:54</td>
<td>Wed Jun 30 09:54</td>
<td>SOI-02h18m</td>
<td>Cassini should be in science attitudes and will not be communicating with Earth; otherwise communication possible</td>
<td>Cassini should be in science attitudes and will not be communicating with Earth; otherwise communication not possible</td>
</tr>
<tr>
<td>183T03:33</td>
<td>Jul 01 04:57</td>
<td>Wed Jun 30 09:57</td>
<td>SOI-02h21m</td>
<td>Cassini should be in science attitudes and will not be communicating with Earth; otherwise communication not possible</td>
<td>Cassini should be in science attitudes and will not be communicating with Earth; otherwise communication not possible</td>
</tr>
<tr>
<td>183T04:08</td>
<td>Jul 01 05:32</td>
<td>Wed Jun 30 10:32</td>
<td>SOI-02h56m</td>
<td>Turn to protective attitude for descending ring-plane crossing</td>
<td>Cassini should be in science attitudes and will not be communicating with Earth; otherwise communication not possible</td>
</tr>
<tr>
<td>183T04:09</td>
<td>Jul 01 05:33</td>
<td>Wed Jun 30 10:33</td>
<td>SOI-02h57m</td>
<td>Cassini emerges from behind Saturn (and is behind A ring)</td>
<td>Cassini should be in science attitudes and will not be communicating with Earth; otherwise communication not likely</td>
</tr>
<tr>
<td>183T04:20</td>
<td>Jul 01 05:44</td>
<td>Wed Jun 30 10:44</td>
<td>SOI-03h08m</td>
<td>Cassini emerges from behind A ring as seen from Earth</td>
<td>Cassini should be in science attitudes and will not be communicating with Earth; otherwise communication not possible</td>
</tr>
<tr>
<td>183T04:34</td>
<td>Jul 01 05:58</td>
<td>Wed Jun 30 10:58</td>
<td>SOI-03h22m</td>
<td>Descending ring-plane crossing</td>
<td>Distance = 158,500 km (98,500 miles); HGA is oriented to dust ram as directed by background sequence</td>
</tr>
<tr>
<td>183T05:36</td>
<td>Jul 01 07:00</td>
<td>Thu Jul 01 12:00</td>
<td>SOI-04h24m</td>
<td>Spacecraft returns to Earth-point; SOI data playback begins</td>
<td>Double playback of SOI science &amp; engineering data for 19.5 hours; data played back over Madrid, then Goldstone</td>
</tr>
<tr>
<td>183T05:48</td>
<td>Jul 01 07:12</td>
<td>Thu Jul 01 12:12</td>
<td>SOI-04h36m</td>
<td>Open main engine cover</td>
<td>Main engine cover is opened for upcoming post-SOI maneuver</td>
</tr>
<tr>
<td>183T09:25</td>
<td>Jul 01 10:49</td>
<td>Thu Jul 01 03:49</td>
<td>SOI-08h13m</td>
<td>Switch to reaction wheel control</td>
<td>Spacecraft has been controlled with thrusters since before SOI; now reaction wheel control is appropriate</td>
</tr>
<tr>
<td>183T11:15</td>
<td>Jul 01 12:39</td>
<td>Thu Jul 01 05:39</td>
<td>SOI-10h03m</td>
<td>First SOI images returned</td>
<td>Post-SOI images of Saturn and rings are retrieved from recorders</td>
</tr>
</tbody>
</table>
The first critical commands execute 29 hours prior to the start of the burn. At one hour and 45 minutes before the burn, the orbiter switches to the low-gain antenna (LGA) communication mode which will be used to track the orbiter as closely as possible during the burn. This mode also turns off the downlink transmitters to conserve power; only the carrier signal is maintained. The carrier-only signal is likely to be received during about half of the maneuver; when Cassini passes behind Saturn’s A and B rings, no signal is likely.

There are seven major turns that are part of the SOI period, as follows. The first four are commanded as part of the critical sequence; the remaining three are commanded in the background sequence, after burn completion.

- Turn off Earth-point to high-gain antenna (HGA) to incoming dust direction, star trackers to Saturn North Pole
- Turn to Burn orientation (after ascending ring-plane crossing)
- Turn during burn (yaw steering) to keep main engine in proper orientation
- Turn to Earth (after burn complete)
- Turn to view Saturn and Rings (post-burn science)
- Turn for DRPC (HGA to RAM, SRU to Saturn North Pole
- Turn to Earth for post-burn playback

One hour and 25 minutes before the burn, the spacecraft turns to orient the high-gain antenna (HGA) to the incoming dust direction. Cassini crosses through Saturn’s ring plane at a radius of 158,500 km – between the F and G rings (both before and after the burn). This location is considered safe; however, to protect the spacecraft as much as possible, it is prudent to use the HGA to protect the spacecraft like an umbrella from any dust that may be present. The main engine cover is open before the ascending ring-plane crossing because there is not time to perform and confirm an open cycle between the ring crossing and the burn start.

After the ascending ring-plane crossing, the spacecraft turns to the burn attitude, opens latching valves to pressurize the propellant system, and initiates the orbit insertion burn.

The SOI maneuver is a 96.4-minute main engine burn with a total ΔV of 626 m/s (1400 mph speed change). Cassini achieves capture around Saturn after about 78 minutes of main engine firing, and the remaining time is used to reduce the initial orbit period. The SOI maneuver places the spacecraft in an initial orbit with a periapsis radius of 1.3 Rs, apoapsis radius of 150.5 Rs, a period of 116 days, and an inclination of 16.8°.

An accelerometer will end the burn when the required velocity change is obtained. The SOI burn duration is also controlled by an energy based algorithm which will insure that the engine burns until the proper orbit is achieved. The spacecraft will be steered at a constant angular rate of about 0.008 °/sec and the engine gimble actuators (EGAs) will keep the main engine pointed along the velocity vector during the burn. The spacecraft will turn about 46° degrees during the SOI burn to maximize the thrust efficiency. The burn will be terminated based on an advanced, intelligent energy cut-off algorithm (“smart burn”).

2.3 FAULT PROTECTION

Fault protection is customized for SOI; all required engineering components are redundant and available to ensure the burn has every chance for successful completion. Both Inertial Reference Units will be operating; star updates will be done during the SOI burn but vibrations set up by the main engine firings may cause smearing or other problems with
Possible Dust Regions Near Cassini Orbit Insertion

- **Janus / Epimetheus**
  - R: 149,775-153,055 km
  - Z: ±1065 km

- **G ring**
  - R: 165,000 - 176,000 km
  - Z: ±720 km

- **Mimas horseshoe**
  - R: 181,170 - 189,870 km
  - Z: ±4950 km

- **Cassini RPX**
  - 158,500 km

- **Cassini (in & out)**

- **Voyager 2**
  - Voyager 1 (not shown) crossed Saturn’s ring plane at R = 1,190,000 km.

**Distance from Saturn (10^3 km and Rs)**

**Possible Dust Regions Near Cassini Orbit Insertion**

- **P11 out** 166,414 km
- **V2** 171,300 km
- **P11 in** 175,645 km

**Note:**

D. Seal 2004 May 26
### SOI SUMMARY

<table>
<thead>
<tr>
<th>Pre-Quiet Period</th>
<th>Quiet Period</th>
<th>ARPC</th>
<th>SOI Burn</th>
<th>Post-Burn Period</th>
<th>DRPC</th>
<th>Downlink to Earth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epoch</td>
<td>Start at turn to safe attitude Day 182 23:47:00, continue until SOI burn start 183 01:12:00</td>
<td>start at burn start 183 01:12:00, ends at end of critical sequence 183 03:07</td>
<td>Start at end of critical sequence 183 03:07, ends at turn to safe for DRPC 04:08</td>
<td>Start at safing turn for DRPC 183 04:08 ends at star of Downlink to Earth 05:36</td>
<td>Start beginning of downlink 05:36, end after D/L of critical sci and engr data ~ 19.5 hrs later.</td>
<td></td>
</tr>
<tr>
<td>Prior to QP</td>
<td>~S-8 day - Start Day 175 0:0:0/</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Day 175)</td>
<td>ends at turn to safe attitude for ARPC 182 23:47:00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ME Cover</td>
<td>Open prior to TCM 20 (S-40d)</td>
<td>Open for burn - Critical Sequence closes cover after burn ends</td>
<td></td>
<td></td>
<td>Closed</td>
<td></td>
</tr>
<tr>
<td>SSRs</td>
<td>Two SSRs, since Oct 2003</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spacecraft</td>
<td>Defined by Science, downlink daily</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Orientation</td>
<td>HGA Earth pointed, secondary axis is +X to Saturn North Pole</td>
<td>HGA to particle RAM, SRU up, Probe down</td>
<td>ME toward velocity direction. Yaw steering, SRU up, ORS toward Saturn, boom away from Saturn parallel to rings</td>
<td>HGA initially to Earth, followed by turn to view rings and Saturn</td>
<td>HGA to particle RAM, Probe looking down, SRU up, boom parallel to rings</td>
<td>HGA Earth pointed, +X (SRU) up, turn to Earth to call home and D/L data</td>
</tr>
<tr>
<td>Instruments ON</td>
<td>approach science</td>
<td>Strawman has CAPS, CDA, MAG, MIMI, &amp; RPWS with power</td>
<td>Any (except RADAR, RSS) ON, (Science FPW</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Science</td>
<td>Yes</td>
<td>Restricted*</td>
<td>Yes*</td>
<td>Yes*</td>
<td>Normal Op Mode power restrictions</td>
<td></td>
</tr>
<tr>
<td>Attitude control</td>
<td>RWA</td>
<td>RCS</td>
<td>RCS</td>
<td>RCS</td>
<td>RCS</td>
<td></td>
</tr>
<tr>
<td>Turns</td>
<td>Saturn viewing allowed, downlink daily to Earth</td>
<td>No turns allowed except S/C turn 60 min prior to ARPC for safe orientation</td>
<td>Turn to burn attitude 10 min after ARPC (wait for Star ID resumption) Turn duration 10 min</td>
<td>0:05:24</td>
<td>Background turns to start science after Turn to earth. Science turns occur between end of burn and prior to DRPC</td>
<td>Turn to Earth after DRPC - Wait 10 minutes for resumption of Star ID</td>
</tr>
</tbody>
</table>

**Instruments ON:** approach science
- Strawman has CAPS, CDA, MAG, MIMI, & RPWS with power
- Any (except RADAR, RSS) ON, (Science FPW
- Normal Op Mode power restrictions

**Spacecraft Orientation:**
- HGA Earth pointed, secondary axis is +X to Saturn North Pole
- HGA to particle RAM, SRU up, Probe down
- ME toward velocity direction. Yaw steering, SRU up, ORS toward Saturn, boom away from Saturn parallel to rings
- HGA initially to Earth, followed by turn to view rings and Saturn
- HGA to particle RAM, Probe looking down, SRU up, boom parallel to rings
- HGA Earth pointed, +X (SRU) up, turn to Earth to call home and D/L data
<table>
<thead>
<tr>
<th>Pre-Quiet Period</th>
<th>Quiet Period</th>
<th>ARPC</th>
<th>SOI Burn</th>
<th>Post-Burn Period</th>
<th>DRPC</th>
<th>Downlink to Earth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turn Times</td>
<td></td>
<td>Turn to burn attitude 00:09:43</td>
<td>Turn to Earth after burn 00:05:24</td>
<td>initial science orientation 00:03:53</td>
<td>safing turn before DRPC 00:08:54</td>
<td>Turn for downlink 00:09:47</td>
</tr>
<tr>
<td>DSN passes</td>
<td>vary daily</td>
<td>Continuous passes through SOI day</td>
<td>continuous coverage but not Earth pointed</td>
<td>continuous coverage but not Earth pointed until end of Burn, which is over Canberra</td>
<td>continuous coverage but not Earth pointed</td>
<td>Turn to Earth over Madrid</td>
</tr>
<tr>
<td>Critical Sequence</td>
<td>loaded 8 weeks prior to periapsis</td>
<td>Critical Sequence executing - ends with close ME cover and turn to Earth</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Safing attitude</td>
<td>Either Sun- or Earth-pointed, depending on type of Fault (HAS algorithm)</td>
<td>HGA to Sun Point</td>
<td>HGA to RAM direction</td>
<td>ME in burn direction, or HGA Sun-Pointed during call home segment</td>
<td>Few minutes of LGA to Sun, thereafter it is HGA to Earth</td>
<td></td>
</tr>
<tr>
<td>Contingency Plans</td>
<td>Autonomous FP in critical sequence</td>
<td>Safing turn is in critical sequence</td>
<td>ME burn in critical sequence, including ME swapping &amp; burn restarts</td>
<td>Call home after burn confirms pointing direction. If safing occurs, no science</td>
<td>ME cover is closed</td>
<td></td>
</tr>
<tr>
<td>Telemetry mode</td>
<td>varies</td>
<td>S&amp;ER10</td>
<td>TWT disabled during burn, record at S&amp;ER10</td>
<td>S&amp;ER2, 3, 5a</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Downlink -</td>
<td>Various antennae &amp; rates</td>
<td>70 m 66.4k - 124.4k</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>PMS checkout done at S-35 days</td>
<td>Disable star ID for RPC</td>
<td>Disable star ID for RPC</td>
<td>one-way LT is 83 minutes.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Restrictions: no power changes, attitude changes, engineering configuration changes (except as needed for ARPC and SOI burn)
Observed Doppler Shift Due To SOI (Representative)

- ARPC
- Noise (No Comm)
- SOI Start
- SOI End
- A-Ring
- B-Ring
- Science Sequence
- Call Home

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star identification. Therefore, star updates during the SOI burn may not be available for attitude control. Good star tracking is expected up to one second before the start of the burn and within one second after the burn. Star updates will be suspended during the ring-plane crossings to minimize the chance of going into safing.

The Cassini spacecraft also carries a redundant main engine in case the primary main engine fails. If the main engine experiences a fault during SOI, it will shut down, and a switch will be made to the redundant main engine after a minimum cooling period. The burn could take up to 5 minutes longer in the baseline case due to engine thrust variations, or hours longer if multiple faults or main engine swaps or engine restarts occur.

If any fault should occur during the burn, the transmitters will be set to standby to maximize the power available to handle the fault, and communications will be suspended until after the burn completes. If the SOI burn completion is delayed due to a spacecraft anomaly, such as switching to the backup main engine, or if the spacecraft goes into safing, the post-burn science background sequence will be deleted and the spacecraft will remain on Earth-line after the burn.

2.4 POST-BURN ACTIVITIES

After the burn has ended the spacecraft reconfigures the spacecraft for normal operations, turns back to Earth-line, and closes the main engine cover (to protect the engine nozzles during the descending ring-plane crossing). Until the background sequence commands high-rate communications, no telemetry will be available. At most about one minute of high-rate telemetry may be received if the ground antennas lock up to the telemetry very quickly. Thereafter, the spacecraft turns off Earth to conduct post-burn unique science.

Shortly after the critical sequence ends, the Ion and Neutral Mass Spectrometer cover is jettisoned. After about an hour of post-burn science, the spacecraft again orients the HGA towards the incoming dust direction for the descending ring-plane crossing. About 45 minutes of further science is collected, and then the spacecraft turns back to Earth to play back data from the critical sequence execution and post-burn science. This will be the first appreciable communication with the spacecraft since before SOI.

An opportunity to observe Titan occurs on the day after SOI. The initial SOI clean-up TCM occurs two and a half days after SOI, and primarily corrects orbital period errors from the SOI burn. The Solar Conjunction (3° SEP) period begins on 3 July at 08:53 and continues until 12 July at 15:55. A final SOI clean-up maneuver is planned for SOI + 16 days.

2.5 SOI DATA RECORDING AND PLAYBACK

This section describes the SSR strategy for the data recorded just before and after SOI, as well as, the first non-targeted Titan flyby named T0 which occurs ~1.3 d after the end of the SOI burn. The time period addressed spans from the transition to SOI telemetry mode during the critical sequence (2004-183T19:00) to the end of the second T0 playback (2004-185T23:06). The close proximity of the T0 observations to the SOI playback affects the SOI playback strategy since T0 data will overwrite early MAG non-critical science data once that data has been played back twice. Since T0 closest approach is only 9.5 h after the end of the two SOI playback passes, SOI downlink capacity is limited, i.e., there is insufficient time for additional SOI playback passes without deleting the important T0 observations.

During this time period the SSR records science and engineering data to partitions 4 and 6. P5 is unused during this time period and is essentially set to zero size (10 frames). P6 is set to its usual 25596 frames (225 Mbit) and P4 is the remainder, 203174 frames (1788 Mbit ). Science recording and playback will be managed by the background sequence.
During the last ~32.1 h of the critical sequence which ends shortly after the SOI burn, MAG TWT science observations and associated house-keeping and engineering are recorded to A4, full engineering recorded to A6, AACS data recorded to B4, and AACS and CDS online data recorded to B6. During the ~2.5 h time period from the end of the critical sequence to the start of the first post-SOI playback, SOI TWT science observations and associated housekeeping and engineering are recorded to B4, full engineering recorded to B6, no data recorded to A4, and CDSonline data recorded to A6.

Overlapping Madrid and Goldstone 70m passes are then used to playback all MAG and SOI TWT science observations twice, one complete playback to each station, and selected portions of critical engineering data are also played back twice. Note that only a portion of the P6 engineering data is played back due to downlink capacity limitations. Since the SOI/T0 data is of such high science value, lockup times and data rate playback pauses are double the nominal tour durations, i.e., are to set to 10 min. and 2 min., respectively.

A detailed time ordered description of the SSR strategy is as follows. When the telemetry mode switches to S&ER10 during the critical sequence (2004-181T19:00), all record and playback pointers are set to zero, ping-pong is enabled (standard tour configuration), and a new data policing table is issued. MAG TWT observations are written to A4 throughout the critical sequence. The table below lists the begin and end epochs, data volume, and contents of recorded data that is to eventually be played back. Any non-standard record pointer management is also noted in the Table. All MAG TWT science observations will be played back twice but only a portion of the A6 critical sequence engineering data is to be played back twice due to downlink capacity limitations. By agreement with the Spacecraft Office, the portion of A6 to be played back ranges from SOI burn start ~7h to the start of the Madrid playback. The data policing table guarantees no ping-pong to SSR B and leaves room for real-time MAPS and engineering recorded to the partition being played back.

<table>
<thead>
<tr>
<th>Partition</th>
<th>Start Epoch of Recorded Data for Later P/B (SCET)</th>
<th>End Epoch of Recorded Data for Later P/B (SCET)</th>
<th>Record Duration (h:mm:ss)</th>
<th>Non-standard Initial Record Pointer Location?</th>
<th>Total Recorded Data to be Played Back (Mb)</th>
<th>Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>DATA TO BE PLAYED BACK</td>
<td>TWICE BEFORE END OF DOY 183</td>
<td>MAD AND GLD PASSES</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A4</td>
<td>2004-181T19:00:00</td>
<td>2004-183T03:06:40</td>
<td>32:06:40</td>
<td>N</td>
<td>1639.9</td>
<td>MAG TWT science obs</td>
</tr>
<tr>
<td>A6</td>
<td>2004-182T18:12:00</td>
<td>2004-183T05:36:00</td>
<td>11:24:00</td>
<td>N</td>
<td>58.3</td>
<td>Engr. from SOI burn start -7h to start MAD p/b</td>
</tr>
<tr>
<td>B4</td>
<td>2004-183T03:06:40</td>
<td>2004-183T05:36:00</td>
<td>02:29:20</td>
<td>N</td>
<td>1693.9</td>
<td>SOI TWT science obs</td>
</tr>
<tr>
<td>B6</td>
<td>2004-183T03:06:40</td>
<td>2004-183T05:36:00</td>
<td>02:29:20</td>
<td>N</td>
<td>14.7</td>
<td>Engr. From end critical seq. to start MAD p/b</td>
</tr>
<tr>
<td>DATA TO BE PLAYED BACK</td>
<td>ONCE DURING DOY 184 and 185</td>
<td>GLD PASSES</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A4</td>
<td>2004-184T01:06:00</td>
<td>2004-184T17:51:00</td>
<td>16:45:00</td>
<td>Y (set to 1660 Mb)</td>
<td>912.0</td>
<td>TOST T0#1 science obs</td>
</tr>
<tr>
<td>A4</td>
<td>2004-184T20:36:00</td>
<td>2004-185T14:06:00</td>
<td>17:30:00</td>
<td>Y (set to 1660 Mb)</td>
<td>923.5</td>
<td>TOST T0#2 science obs</td>
</tr>
</tbody>
</table>

Upon completion of the critical sequence (183T03:06:40), a command is issued to swap to SSR B. A new data policing table is then issued which ensures no ping-pong back to SSR A, and leaves room for real-time MAPS and engineering during playback. SOI TWT science observations are recorded to B4 until start of Madrid playback. All SOI TWT science observations will be played back twice but only a portion of the B6 engineering data is to be played back twice due to downlink capacity limitations. By agreement with SCO, the portion of B6 to be played back ranges from the end critical sequence to the start of the Madrid playback, i.e., the same time period during which SOI TWT science observations are conducted.

The following table lists in time order the playback begin and end epochs, data volume, and contents for each partition played back. Note the amount of real-time MAPS and engineering data written to the partition as it is played back is also included since this data

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must also eventually be played back. Any non-standard playback pointer management is also noted in the table.

At start of MAD playback (183T05:36), playback pointers on A6 and B6 are set to predetermined addresses. The A6 playback pointer is set to the location of critical sequence engineering data at SOI burn start - 7 hours (2004-182T18:12). The B6 playback pointer is set to the location at the end of critical sequence (183T03:06:40). Issue new data policing table, which ensures science data in P4 will not be overwritten during playback by MAPS and engineering data recorded during playback. Issue priority playback order [A6, A4, B6, B4]. Let playback run to completion.

Note the Madrid/Goldstone overlap period begins in the middle of B4 playback, which dictates that the lesser of the two station downlink rates must be used so that both stations can receive the data. Both stations get two full playbacks of all MAG and SOI TWT observations; Madrid receives early portion of B4. Madrid/Goldstone overlap receives latter portion of B4, and Goldstone receives early portion of B4 again.

<table>
<thead>
<tr>
<th>Partition</th>
<th>P/B Number</th>
<th>DSN 70m Station</th>
<th>Begin P/B Epoch (SCET)</th>
<th>End P/B Epoch (SCET)</th>
<th>P/B Duration (hh:mm:ss)</th>
<th>Non-standard Initial P/B Pointer Location?</th>
<th>Engineering and MAPS (E &amp; MAPS) Recorded to Partition During P/B (Mb)</th>
<th>Total Data Played Back (Mb)</th>
<th>Data Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>A6</td>
<td>1</td>
<td>MAD</td>
<td>2004-183T05:36:00</td>
<td>2004-183T06:02:54</td>
<td>00:26:54</td>
<td>Y (set to 136.8 Mb)</td>
<td>13.0</td>
<td>N</td>
<td>71.3</td>
</tr>
<tr>
<td>A4</td>
<td>1</td>
<td>MAD</td>
<td>2004-183T06:02:54</td>
<td>2004-183T11:09:57</td>
<td>05:07:03</td>
<td>N (set to 141.6 Mb)</td>
<td>16.6</td>
<td>126.3</td>
<td>1766.2</td>
</tr>
<tr>
<td>B4</td>
<td>1</td>
<td>GLD</td>
<td>2004-183T11:09:57</td>
<td>2004-183T11:12:22</td>
<td>00:02:25</td>
<td>Y (set to 141.6 Mb)</td>
<td>16.6</td>
<td>52.6</td>
<td>1012.9</td>
</tr>
<tr>
<td>B4 (cont.)</td>
<td>1</td>
<td>MAD / GLD</td>
<td>2004-183T13:50:59</td>
<td>2004-183T16:14:15</td>
<td>02:23:16</td>
<td>N (set to 141.6 Mb)</td>
<td>17.5</td>
<td>47.5</td>
<td>781.1</td>
</tr>
<tr>
<td>B4 p/b margin &amp; MAPS</td>
<td>1</td>
<td>MAD / GLD</td>
<td>2004-183T16:14:15</td>
<td>2004-183T16:20:59</td>
<td>00:06:44</td>
<td>N</td>
<td>2.2</td>
<td>2.2</td>
<td>E &amp; MAPS</td>
</tr>
<tr>
<td>A6</td>
<td>2</td>
<td>GLD</td>
<td>2004-183T16:20:59</td>
<td>2004-183T16:34:53</td>
<td>02:00:54</td>
<td>Y (set to 136.8 Mb)</td>
<td>4.6</td>
<td>79.9</td>
<td>1863.0</td>
</tr>
<tr>
<td>A4</td>
<td>2</td>
<td>GLD</td>
<td>2004-183T16:34:53</td>
<td>2004-183T21:26:50</td>
<td>04:51:57</td>
<td>Y (set to 141.6 Mb)</td>
<td>16.6</td>
<td>96.8</td>
<td>1103.2</td>
</tr>
<tr>
<td>B6</td>
<td>2</td>
<td>GLD</td>
<td>2004-183T21:26:50</td>
<td>2004-183T21:29:23</td>
<td>00:02:33</td>
<td>Y (set to 141.6 Mb)</td>
<td>17.5</td>
<td>17.5</td>
<td>1020.4</td>
</tr>
<tr>
<td>B4</td>
<td>2</td>
<td>GLD</td>
<td>2004-183T21:29:23</td>
<td>2004-184T01:06:00</td>
<td>03:36:37</td>
<td>Y (set to 141.6 Mb)</td>
<td>17.5</td>
<td>71.9</td>
<td>1103.2</td>
</tr>
</tbody>
</table>

**Note** for total B4 data p/b from 183T11:12:22 to 16:14:15, total data p/b = 1794.0 Mb, total p/b duration 05:01:53.

**Note** 5 min. lockup time assumed for TOST1, all other p/b's assumed 10 min. lockup. All assume 2 min. p/b pause per rate change
Playback continues 00:06:44 beyond the predicted end of the first priority playback list to 183T16:20:59 to provide playback margin at which point the second playback of the data begins. Reset the playback pointer on A4 to 0 Mbit (top), B4 to 65 Mbit, and A6 and B6 to the same predetermined addresses as at start of the Madrid playback. B4 playback pointer should not be reset to 0 Mbit (top) since the record pointer wraps past 0 Mbit (to ~8 Mbit) by the end of the Madrid playback. The B4 playback pointer needs to be set ahead of the record pointer to obtain a full second playback. Instead, the initial B4 record pointer location is set to 65.0 Mbit since this location is well past the record pointer and is 2 Mbit before start of SOI TWT science observations. (The first 67.0 Mbit on B4 is critical sequence AACS data which need never be played back since this data will already receive multiple playbacks from other partitions – Spacecraft Office concurrence received. Note this first portion of B4 is still played back once over Madrid).

Reissue SSR playback order [A6, A4, B6, B4] for second round of playbacks over Goldstone. Playback until end of Goldstone pass (184T01:06:00). Data policing tables ensure that real-time MAPS and engineering recorded during playback overwrite no more than 75.1 Mbit of the earliest MAG TWT non-critical science data and no more than 13.2 Mbit of the SOI TWT critical data. Note this assumes that science instruments will record the full data volume allotted by the given data policing tables. 71.9 Mbit of real-time MAPS and engineering data are recorded to B4 during the Goldstone playback are not played back until T0 II playback on doy 185 since insufficient downlink capacity is available on doy 183 to playback the entire B4 partition. Since this is not critical SOI TWT science data, the delay is acceptable.

At the end of the first Goldstone playback (184T01:06:00), set the record pointer on A4 to 1660 Mbit and the playback pointer to just behind it (SSR empty). A data policing table is loaded to cap T0 I record to 912 Mbit. The record pointer is set to 1660 Mbit instead of 0 Mbit to take advantage of the fact that the last ~148 Mbit of A4 contains no MAG TWT science data. By first overwriting the last 128 Mbit of A4 first (20 Mbit of the 148 Mbit available are maintained as margin with respect to the end of the science data), less MAG TWT early science data are overwritten by T0 data. For example, the total T0 I data recorded during both observation and playback is 1001.8 Mbit. By setting the initial record pointer location to 1660 Mbit, the record pointer only advances to 873.8 Mbit, rather than 1001.8 Mbit, which is an important difference since data beyond the first ~817 Mbit on A4 are deemed critical science by the MAG TWT.

Every effort was made to simplify SOI playback but it still departs from standard tour playbacks since dual playbacks are required and because downlink capacity limitations do not always permit full partition playbacks.

2.6 T0 DATA RECORDING AND PLAYBACK

Observations of the first non-targeted Titan flyby named T0 commence at the end of the Goldstone DOY 183 playback. There are two T0 observation periods, referred to as T0 I and T0 II, which are separated by a short playback pass. T0 data is only recorded to SSR A. By agreement with the MAG TWT, early observations in A4 are overwritten by T0 observations once two attempts have been made to playback all the MAG TWT data.

Following the 16:45:00 duration T0 I observation period ending at 184T17:51:00, SSR priority playback order [A4] is issued. Load new data policing table which caps real-time MAPS and engineering data recorded during playback at 90 Mbit. Playback over short (00:02:45 duration) Goldstone 70m pass beginning at 184T17:51. Unlike other SOI/T0 playbacks, a 5 min. lockup time is assumed since there is insufficient downlink capacity to support a 10 min. lockup time. Following playback, TOST recording will have progressed
to ~8.4 Rs point in MAG TWT data (the record pointer will advance to 873.8 Mbit per above
discussion).

The second T0 observation period, T0 II, begins upon completion of the short T0 I
playback. At 184T20:36:00, set record pointer on A4 to 1660 Mbit, playback pointer to just
behind it (SSR empty) in the same manner as for the T0 I observations. A new data policing
table is loaded to cap T0 II record at 924 Mbit. Record 17:30:00, issue SSR priority playback
order [B4, A4]. Load a new data policing table which caps MAPS and engineering data
recorded during playback at 284 Mbit. Playback over 9h Goldstone 70m OTM pass until
 completion. The B4 playback pointer is unchanged from its location at the end of the last
Goldstone playback on doy 183. B4 is part of priority playback list in order to playback the
MAPS and engineering data recorded during doy 183 B4 playback which spanned 183T
21:29:23 to 183T01:06:00. During playback, 68.5 Mbit of MAPS and engineering are written
to B4 advancing the record pointer such that 81.7 Mbit of B4 SOI TWT science observations
will be overwritten by the end of the T0 II playback.

Following T0 II playback, recording in A4 will have progressed to ~6.8 Rs point in MAG
TWT data (the record pointer will have advanced to 1010.8 Mbit). More MAG TWT science
data is overwritten by T0 II than T0 I since T0 II records 11.5 Mbit more science
observations (Table 7.3) and 125.4 Mbit more MAPS and engineering during playback
(Table 7.4) due to the much longer playback duration for T0 II.

Note that T0 II has a downlink capacity margin of nearly 1 Gbit which would be available
in a contingency scenario to replay selected portions of critical science that may have not
been played back to Project satisfaction. An additional 768 Mbit of downlink capacity could
be gained by never playing back the B4 MAPS and engineering data recorded from 183T
21:29:23 to 183T01:06:00.

2.7 CONTINGENCY CRITICAL SCIENCE PRESERVATION

Nominal tour MAG TWT observations commence recording to A4 at completion of the T0
II playback. At 185T23:06, repartition SSR and command per nominal tour. If any
contingency requires that some data be played back again, significant margin exists during
the 9h 70m Goldstone pass beginning 186T14:06. If this is not acceptable, the strategies are
as follows:

- If only B4 critical SOI science data needs to be preserved, ping-pong is disabled thus
  protecting B4 from further recording; B4 could also be write-protected.

- If only A4 critical MAG science (i.e., the last 629.2 Mbit of MAG TWT science) needs
to be preserved, the spacecraft switches to SSR B and ping-pong is disabled, thus
  protecting A4 from further recording; A4 could also be write-protected.

- If science data on both SSRs needs to be preserved, the data policing tables which
  allow instruments to record data are zeroed out, preventing new science data from
  overwriting SOI data on both SSRs.

Any of the above strategies is sufficient to protect the relevant partitions until past solar
conjunction when further playbacks are possible.