Cassini Science Planning Process

Brian Paczkowski
Cassini Science Planning Manager, JPL

Trina Ray
Cassini Science Planning Engineer, JPL
Mission Overview

• Combined Saturn orbiter and Titan atmospheric probe (Huygens)
  – Three-axis stabilized spacecraft (reaction wheels and thrusters)
  – 27 science investigations from 12 orbiter, 6 Huygens instruments
  – Once fixed high-gain antenna, two low-gain antennas
  – Three RTGs for power
  – Redundant main engines, attitude thrusters (8)
  – Two Solid-State Recorder of 2.0 Gbits each

• Launched 15 October 1997 on Titan IV/Centaur into 6.7-year Venus-Venus-Earth-Jupiter trajectory to arrive on 1 July 2004

• 4 year Prime Mission
  – 75 orbits
  – 44 targeted Titan flybys
  – 9 targeted icy satellite flybys
  – 41 sequence loads
Tour Overview
Tour Overview (Cont’d)

North Pole View

Side View
## Mission Comparison

<table>
<thead>
<tr>
<th>CHARACTERISTIC</th>
<th>VOYAGER</th>
<th>GALILEO</th>
<th>CASSINI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orbits</td>
<td>6 (flybys)</td>
<td>11</td>
<td>75</td>
</tr>
<tr>
<td>Average Orbit Duration</td>
<td>120 days (flyby)</td>
<td>8 weeks (5 wks - 8 wks)</td>
<td>3 weeks (1 wk - 3 months)</td>
</tr>
<tr>
<td>Operations Environment</td>
<td>Centralized</td>
<td>Centralized</td>
<td>Distributed</td>
</tr>
<tr>
<td>Prime Mission Duration</td>
<td>2 years</td>
<td>2 years</td>
<td>4 years</td>
</tr>
<tr>
<td>Total Mission Data Volume</td>
<td>~4,000 Gbits</td>
<td>2 Gbits</td>
<td>~3,000 Gbits</td>
</tr>
<tr>
<td>Scan Platform</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Maximum Turn/Slew Rates</td>
<td>1°/sec</td>
<td>1°/sec</td>
<td>0.4°/sec-RCS 0.2°/sec-RW</td>
</tr>
<tr>
<td>Power Modes</td>
<td>1</td>
<td>8</td>
<td>12</td>
</tr>
<tr>
<td>Recorder Volume</td>
<td>.5 Gbits</td>
<td>.9 Gbits</td>
<td>4 Gbits</td>
</tr>
<tr>
<td>Imaging Instruments</td>
<td>2</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>Science Instruments</td>
<td>11</td>
<td>12 Orbiter</td>
<td>12 Orbiter</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6 Probe</td>
<td>6 Probe</td>
</tr>
<tr>
<td>Science Plan Development Time</td>
<td>9:1</td>
<td>5:1</td>
<td>3:1</td>
</tr>
<tr>
<td>Sequence Loads/Orbit (Average)</td>
<td>10 loads/flyby</td>
<td>3 (1 encounter, 2 orbital cruise)</td>
<td>4-5 weeks (n orbits/load)</td>
</tr>
<tr>
<td>Targets &amp; Periapses/Load (Average)</td>
<td>10 loads/flyby</td>
<td>1 periapse, 1 satellite</td>
<td>2 periapse, 2 satellites</td>
</tr>
<tr>
<td>Sequence Load Size</td>
<td>2.5 Kwords</td>
<td>16 Kwords</td>
<td>150 Kwords</td>
</tr>
<tr>
<td>Science Operations Staff (JPL)</td>
<td>~60</td>
<td>60</td>
<td>23</td>
</tr>
<tr>
<td>Investigation Team Size</td>
<td>~150</td>
<td>187</td>
<td>254</td>
</tr>
</tbody>
</table>

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Science Planning Challenges

- Distributed Operations
  - Remoteness & Timezones
  - Mismatch between spacecraft design and operations environment
- Lack of Scan Platform
  - Instrument pointing constraints
  - Downlink/observation time-sharing
- Simultaneous Ops
  - Long-Term/Short-Term Science Planning Development
  - Sequence development and execution
- FSW/GSW development
  - Timeliness of software development
- Complexity of Spacecraft Operations
  - Pointing constraints
  - Power modes
  - Telemetry modes
- Tour Selection
  - Discipline focused groups
- PSG ownership of process
- Funding & Schedule Drivers
## Science Planning Timeline

<table>
<thead>
<tr>
<th>When</th>
<th>What (goals)</th>
<th>Who</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 years before PM</td>
<td><strong>Tour Design</strong> (maximize science opportunity)</td>
<td>Science Community, Mission Planning (some Spacecraft)</td>
<td>Science experiment trade-offs, navigation and uplink development capabilities.</td>
</tr>
<tr>
<td>4 years before PM</td>
<td><strong>Integration</strong> (negotiate best science compromise)</td>
<td>Science Planning, Science Community (some Spacecraft, some Mission Planning)</td>
<td>Break up entire mission by science discipline and negotiate shared resources (pointing, power, telemetry, and data volume), lack of a scan platform makes this a challenge.</td>
</tr>
<tr>
<td>2 years before PM</td>
<td><strong>Implementation</strong> (validate basic sequence design)</td>
<td>Science Planning, Science Operations Spacecraft Team (some Mission Planning)</td>
<td>3 chances to get a skeleton sequence of the shared resources in place and validated, distributed operations makes this a challenge.</td>
</tr>
<tr>
<td>20 weeks before execution</td>
<td><strong>Adaptation</strong> (update integrated plan)</td>
<td>Science Planning, Science Community (some Spacecraft, some Mission Planning)</td>
<td>Update integrated plan based on new discoveries, science data analysis, spacecraft/instrument performance changes, etc.</td>
</tr>
<tr>
<td>15 weeks before execution</td>
<td><strong>Implementation Update</strong> (update basic sequence design)</td>
<td>Science Planning, Science Operations Spacecraft Team, (some Mission Planning)</td>
<td>1 chance to update the skeleton sequence to any updated science compromises and/or new discoveries.</td>
</tr>
<tr>
<td>10 weeks before execution</td>
<td><strong>Sequencing</strong> (validate entire sequence)</td>
<td>Sequence Lead, Science Operations, Spacecraft Team (some Science Planning)</td>
<td>2 cycles to create a complete sequence, all commands in place and validated, complexity of spacecraft and plans make this a challenge.</td>
</tr>
</tbody>
</table>

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Science Planning Process Selection

- **Integration**
  - Option 1
    - Small science-savvy group at JPL responsible for the integration of the Tour.
      - Cons: Not scientifically optimized; huge workload on small group; politics of empowerment
      - Pros: Rapid integration; problem solution inheritance
  - Option 2
    - Large single PSG group that integrates the entire Tour except the target flyby.
      - Cons: Large membership makes for slow process; large group dynamics issues
      - Pros: Distribute workload amongst all PSG members; problem solution inheritance; science community representation;
  - Option 3
    - Smaller PSG groups with responsibilities split up by science discipline and/or target body.
      - Cons: Better communication/coordination between integration groups; some members needed to support multiple groups
      - Pros: 4 parallel efforts increases workforce utilization; discipline/target body focused group; PSG co-leadership of group (empowerment); optimized science plan

- **Implementation**
  - Significant inheritance from Galileo Science Planning Operations Process
Science Planning Process Schedule/Flow

Long-Range Mission Planning Process

- SOP Development
  - Tour Atlas
- Aftermarket Process
  - Activity Request Process
- SOP Update Process
  - Integration/Conflict Resolution & Merge Process
- Science and Sequencing Update Process (SSUP)
  - SPVT Implementation Process

MP Updates

Tour SOP

Uplinked Sequences and R/T Commands

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Science Operations Plan (SOP) Process Overview

Space Operations Plan (SOP) Process Overview

- Science Instrument Teams
- DWG Activities
- Detailed Activity Requests
- Cross Discipline Workshops
- Spacecraft Office Instrument Operation Team
- Detailed Activity Requests
- CIMS Data
- Output
  - Integrated science plan
  - Time-ordered listings
  - Prime instrument allocation of time
  - S/C orientations
  - APGEN timelines
  - Data volume allocations to instrument teams
  - Opmodes vs. time
  - Downlink data strategy
  - Tour templates
  - Est. Consumable usage
- Target Working Team Integration Activities (TOST, SOST, etc.)
  - Hard conflict resolution, Review/Approve plans
- Project Science Group and Project Scientist
- Merge Products
- SPVT Implementation
- SOP
- Integration/Conflict Resolution

Activity Request

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Science Planning Process Current Status

- **SOP Integration**
  - Approach Science: 100% complete on May 2003.
  - Tour Science: 100% complete on January 2004.

- **SOP Implementation**
  - Approach Science: 100% complete and 2 of 3 sequences have executed on board the spacecraft.
  - Tour Science: A total of 68% (28 out of 41) of the Tour sequences “complete” and “on-the-shelf”.

- **Aftermarket (Integration Update)**
  - Updated the plans for 3 of 41 sequences.

- **SOP Update**
  - Completed 3 of 41 sequences.
Lessons Learned

- Better use of concurrent engineering practices related to development & operations
  - Consideration of operability factored into spacecraft development
- Distributed operations is not the low cost operations option
  - Redundant hardware and software infrastructure
  - Training and cross-training
- Exercising the systems as early as possible prior to prime mission
  - Jupiter Flyby
  - Verification and Validation (V&V) System Testing
- Effective communication
  - Web-based interactions
- Centralized web-based database critical