Maintaining Aura’s Orbit Requirements Under New Maneuver Operations

Megan Johnson
Jeremy Petersen

Session 1-2
May 05, 2014
Overview

• Background
  – Afternoon Constellation
  – Aura Operational Requirements

• No-slew maneuvers

• Alternate maneuver schemes
  – Mirror pole maneuvers
  – Hybrid maneuver scheme

• Open Issues
Afternoon Constellation
Ground Track

- **SMA control via Drag Make Up (DMU) maneuvers is required** to accurately maintain the ground track
- The ground track must stay on the WRS-2 path for science data collection
- DMU Frequency is driven by atmospheric drag
Sun Synchronous Orbits

- **MLT control via Inclination Adjust Maneuvers (IAMs)** is required to accurately maintain along-track separation between missions and repeatable lighting conditions.
- Nominally perform 3-5 maneuvers per year in the Spring.
- MLT deviations driven by luni-solar pertubations acting on inclination.
- A further mission requirement constricts the **MLT prediction to vary by no more than ± 2 seconds over the course of one year**.

EOS orbit regime: 694 - 711 km
## Aura Orbit Properties

<table>
<thead>
<tr>
<th>Orbital Element</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>WRS-2 Ground Track</strong></td>
<td>18 ± 20 km mission requirement</td>
</tr>
<tr>
<td></td>
<td>18 ±- 10 km operational requirement</td>
</tr>
<tr>
<td><strong>Mean Local Time Aura</strong></td>
<td>13:30:00 to 14:00:00</td>
</tr>
<tr>
<td></td>
<td>8.5 minutes ± 15 seconds w.r.t Aqua</td>
</tr>
<tr>
<td><strong>Mean Local Time Aqua</strong></td>
<td>13:35:00 to 13:36:30</td>
</tr>
<tr>
<td><strong>Semi-major Axis</strong></td>
<td>7077.7 km ± 0.3 km</td>
</tr>
<tr>
<td><strong>Inclination</strong></td>
<td>98.2 ± 0.15 degrees</td>
</tr>
<tr>
<td><strong>Argument of Perigee</strong></td>
<td>90 ± 20 degrees</td>
</tr>
<tr>
<td><strong>Eccentricity</strong></td>
<td>0.0012 ± 0.0004</td>
</tr>
</tbody>
</table>
Slewed vs No-slew Maneuvers

- How can the mission requirements be maintained with an added orbit-normal delta-V?

**Slewed DMUs**

Thrust Vector

(Angle Normal)

(Angle Normal)

**No-Slew DMUs**

Thrust Vector

(Angle Normal)

(Angle Normal)

Aqua: $\Psi = 14.350^\circ$

Aura: $\Psi = 13.493^\circ$
Effect of No-slew Maneuvers

\[
\frac{da}{dt} = \frac{2}{n\sqrt{1-e^2}} \left( e \sin(v) F_R + \frac{p}{r} r F_s \right)
\]

\[
\frac{de}{dt} = \frac{\sqrt{1-e^2}}{na} \left( \sin(v) F_R + \left( \cos(v) + \frac{e + \cos(v)}{1 + e \cos(v)} r \right) F_s \right)
\]

\[
\frac{di}{dt} = \frac{r}{na^2 \sqrt{1-e^2}} F_w \cos(v)
\]

\[
\frac{d\Omega}{dt} = \frac{r}{na^2 \sqrt{1-e^2}} F_w \frac{\sin(v)}{\sin(i)}
\]

\[
\frac{d\omega}{dt} = \frac{\sqrt{1-e^2}}{na^2 e} \left\{ -\cos(v) F_R + \sin(v) \left( 1 + \frac{r}{p} \right) F_s \right\} - \frac{r \cot(i) \sin(v) F_w}{h}
\]

\[
\frac{dM_o}{dt} = \frac{1}{na^2 e} \left\{ (p \cos(v) - 2er) F_R - (p + r) \sin(v) F_s \right\}
\]

Legend:
- \(a\): Semi-major axis
- \(e\): eccentricity
- \(v\): argument of latitude
- \(w\): argument of perigee
- \(n\): mean motion
- \(i\): inclination
- \(r\): radial distance from Earth’s center
- \(t\): time
- \(\Omega\): RAAN
- \(p\): \(a(1-e^2)\)
- \(F_R\): Force parallel to position vector
- \(F_w\): Force in the instantaneous direction of angular momentum vector
- \(F_s\): Force normal to the position vector along the S axis
Benefits of No-slew Maneuvers

• Pros
  – **Simplified** spacecraft commanding
  – **Minimized** required communications coverage
  – **Reduced** science data collection loss per maneuvers
  – **Simplified** maneuver planning for emergency scenarios
  – **Improved** maneuver predictions
  – **Reduced** man hours for maneuver execution

• Cons
  – **Increased** complexity in long and short term maneuver planning
  – **No historical data** for maneuver trending
Maneuver Strategies

- **Frozen Orbit Maintenance**
  - Original strategy to maintain argument of perigee and eccentricity values

- **Mirror Pole Paired Burns**
  - Alternates maneuvers at North and South Pole
  - Each pair cancels out added delta-inclination

- **North Pole Only**
- **South Pole Only**

- **Mirror Node Paired Burns**
  - Alternates maneuvers at Ascending and Descending Nodes

- **Ascending Node Only**
- **Descending Node Only**

- **Hybrid Strategy**
  - Maneuvers are Mirror Pole Paired Burns or Frozen Orbit Maintenance burns depending on the time of year
Mirror Pole Maneuver Strategy

Maneuvering at the poles produces zero net inclination change

Maneuvering at the poles produces zero net RAAN change
No-Slew effect on MLT

- The Mirror Poles strategy accrues the least MLT difference over time
The mirror pole strategy causes the amplitude of the argument of perigee and eccentricity to grow over time.
Hybrid Maneuver Strategy

• Can MLT and Frozen Orbit control be optimized?
  – Want to do mirror pole paired burns directly following Spring IAM series
  – Switch to frozen orbit maintenance maneuvers late in the year to minimize the time the delta-INC can accumulate prior to IAM series

• Case studies:
  – Slewed: all maneuvers used for frozen orbit control
  – All Mirror Pole: no-slew maneuvers
  – All Frozen Orbit: no-slew with frozen orbit control
  – One Mirror Pole Pair: once one pair is completed, switch to frozen orbit control
  – Two Mirror Pole Pairs: once two pairs are completed, switch to frozen orbit control
Hybrid Maneuver Strategy – Eccentricity

**Science requirement +/- 0.0004**

**Maneuver Plan**

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<tr>
<th>Maneuver Plan</th>
<th>Max Eccentricity Difference (4 Years)</th>
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<tbody>
<tr>
<td>All Slew</td>
<td>6.25E-05</td>
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<td>All Mirror Pole</td>
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<td>One Mirror Pole Pair</td>
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**Maneuver Plan**

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<tr>
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<td>3.19</td>
</tr>
<tr>
<td>One Mirror Pole Pair</td>
<td>3.76</td>
</tr>
<tr>
<td>Two Mirror Pole Pairs</td>
<td>5.78</td>
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**Science requirement +/- 20 degrees**

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科学要求：±0.0004

操作计划

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<th>4年内平均接近点的差值（最大）</th>
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<tr>
<td>所有移动</td>
<td>6.25E-05</td>
</tr>
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Hybrid Maneuver Scheme - MLT

- All maneuver strategies maintained the +/- 2 second prediction requirement over one year

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<th>MLT Difference (sec) over one year</th>
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<tr>
<td>All Mirror Pole</td>
<td>0.20</td>
</tr>
<tr>
<td>All Frozen Orbit</td>
<td>0.24</td>
</tr>
<tr>
<td>One Mirror Pole Pair</td>
<td>0.03</td>
</tr>
<tr>
<td>Two Mirror Pole Pairs</td>
<td>0.05</td>
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Conclusion

• No-slew operations bring additional complexity when planning DMU maneuvers
  – Changes to MLT
  – Changes in frozen orbit when compensating for MLT change

• The Mirror Pole Paired maneuver strategy works to maintain MLT but degrades the frozen orbit

• The hybrid maneuver strategy is able to address both concerns by combining the mirror pole paired burns strategy with frozen orbit burns throughout the year
Open Issues

• Further analysis of the effects atmospheric density has on the hybrid maneuver scheme
  – Mirror pole maneuver strategy is effected differently in a low drag environment than a high drag one
  – Frequency of maneuvers will also change when to switch from mirror pole to frozen orbit burns

• Investigate the effect Risk Mitigation Maneuvers (RMMs) on mission requirements

• Lifetime simulation of no-slew operations on Aqua, the Afternoon Constellation lead mission