FUSE On-Orbit Operations

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Outline

• On-orbit Operations Timeline
• The first 6 months
• Preparation for extended mission
• Gyroscope failures
• Reaction wheel failures
• Lessons Learned
## FUSE On-orbit timeline

<table>
<thead>
<tr>
<th>Event Date</th>
<th>Event Description</th>
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<tbody>
<tr>
<td>1999 June 24 -</td>
<td>Launch</td>
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<tr>
<td>2000 Jan,Apr:</td>
<td>Low laser intensity in each gyro</td>
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<tr>
<td>2001 May 30 -</td>
<td>IRU A roll axis fails; begin gyroless S/W development</td>
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<td>2001 Aug,Oct:</td>
<td>low laser intensity in 2 IRU B gyros, 3rd a year later</td>
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<td>2001 November 27-</td>
<td>Yaw RWA fails</td>
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<td>2001 December 10-</td>
<td>Pitch RWA fails</td>
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<td>2002 January 24-</td>
<td>two-RWA controller</td>
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<tr>
<td>2003 April 16 -</td>
<td>load gyroless S/W (ACS,IDS,FES)</td>
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<tr>
<td>2003 July 31</td>
<td>IRU B yaw axis fails; begin 2-gyro operations</td>
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<tr>
<td>2004 September 28-</td>
<td>IRU B pitch axis too noisy, begin 1-gyro operations</td>
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<tr>
<td>2004 December 27-</td>
<td>Roll RWA fails; Resume 3-gyro ops</td>
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<td>2005 March 25</td>
<td>first 1-RWA controller</td>
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<tr>
<td>2005 April 17</td>
<td>IRU B roll axis fails, 2-gyro ops</td>
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<td>2007 July 12</td>
<td>Skew RWA fails</td>
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<tr>
<td>2007 October 18</td>
<td>decommission satellite</td>
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<tr>
<td></td>
<td>2007 April 16 - load gyroless S/W (ACS,IDS,FES)</td>
</tr>
</tbody>
</table>
FUSE Operations

• Mission Operations Team and Science operations both located at JHU.
  – Mission ops
  – Instrument characterization & calibration
  – Observer support
  – Observation planning
  – Data Processing

• Operations were complex: similar to HST, except only one instrument
The first 6 months: 
a large number of small problems

• The 4 co-aligned telescopes did not remain co-aligned
  – TVAC could not replicate effects of varying Sun angles
  – Solved by grouping observations, developing robust alignment procedures
  – Added ~0.5 FTE to ops workload
The first 6 months - 2

- Detector RAM susceptible to SEUs
- Code in PROMs not safe:
  - One HV supply failure mode not protected
- Lost 1-2 days/week reloading code from ground
  - Solved by storing code in spare EEPROM elsewhere and developing autonomous reload procedures
The first 6 months - 3

• Memory leak in instrument script memory
• Not detected in I&T: only apparent after >1 week of continuous operations
• Mission sequence tests longer than 1-2 days impractical with satellite
  – Solved by uploading revised S/W
The first 6 months - 4

• Subtle timing problem caused Fine Error Sensor to hang up ~once/week
  – Depended on positions of guide stars, interrupt timing
  – Not easily reproducible
  – Not caught in I&T due to limited number of test configurations
  – Solved by uploading new S/W.
The first 6 months - 5

- Numerous other minor problems
- Overall workload underestimated
  - Adding only 2 FTEs (~10%) to ops staff made a huge difference
- Can’t predict where problems will arise
  - Need enough staff with cross-training to shift resources where needed
Preparation for Extended Mission

- EM Staffing was to be ~1/2 of Prime mission
- Developed extensive automation of all nominal real-time operations
- Developed automated paging of staff for any off-nominal condition
- Developed secure remote access to control center
Gyro failures

- Problem found in I&T; rework at vendor did not completely fix underlying problem
- Extensive re-design of ACS & instrument S/W
  - Sustaining engineering contracts w/ S/C and instrument subsystem providers
- Lengthy test program
  - More complex than original test program!
    - All combinations of partial sensor complements
  - Flight system inherently less predictable
    - Positive feedback between poor control (RWA failures) & poor rate estimate
- Worked well, but was big effort for small staff
Reaction Wheel Failures

- No hints during I&T
- Problem thought to be due to launch vibrations not aligned with body axes
  - Not part of typical qualification testing!
- Additional rework of flight S/W
- Extensive redesign of ground S/W!
  - New observation planning S/W was bigger effort than the new flight S/W
Lessons Learned - 1

• High-quality optical end-to-end tests are:
  – Difficult to do early
  – Difficult to do well
  – Expensive
  – Priceless
  • Our End-to-End test caught a significant problem that could not have been found at a lower level of integration

• Design of verification tests should receive careful consideration as early as possible
  – Design instruments to facilitate verification

• We put a lot of effort into this, and still didn’t catch everything
Lessons Learned - 2

• High-fidelity flight-ops test bed(s) should be dedicated to the control center beginning 1 year before launch
  – Need not be expensive if planned from day 1
  – Can save a lot of test time during I&T
  – Enables S/W verification testing that would be impractical with satellite
  – Essential for post-launch flight S/W development and testing.
Lessons Learned - 3

• Sustaining engineering contracts for post-launch support are essential.
• TDRSS availability for contingency operations is an enormous help.
• Stringent contamination control is possible at modest cost!