FUSE On-Orbit Operations

Jeff Kruk

Warren Moos

Dennis McCarthy

Outline

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

FUSE On-orbit timeline

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

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!