On-Orbit Anomaly Management and Lessons Learned

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Overview

- Introduction
- Strategy for Implementation
- On-Orbit Anomaly/Supply Chain
- Case Study & Lessons Learned
- Conclusion
Introduction

• On-Orbit anomalies are unexpected conditions that occur almost on all missions. Managing anomalies in space systems are challenging given their complexity and their remote environment.

• The majority of anomalies occurred early in the mission, usually within one year from launch. Anomalies are categorized by cause and equipment type involved.

• A study of past on-orbit anomalies resulted in spacecraft requirements include advances in reliability, particularly for deep space missions and long duration Earth observing platforms.

• Analysis on-orbit experiences provide the basis for effective strategist & paradigms

• Mission operations are significant factors (~ 25% - 60%) of overall mission lifecycle.

• During the last 10 years, mission teams have evolved from separate development teams and separate operational teams to integrate teams for development and operations
## Current GSFC Missions - On-Orbit

### Space Science Mission Operation (SSMO)

<table>
<thead>
<tr>
<th>SMO</th>
<th>Mission Description</th>
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<tbody>
<tr>
<td>1</td>
<td><strong>ACE</strong> Advanced Composition Explorer</td>
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<tr>
<td>2</td>
<td><strong>AIM</strong> Aeronomy of Ice in the Mesosphere</td>
</tr>
<tr>
<td>3</td>
<td><strong>CLUSTER II</strong> ESA’s four-spacecraft Cluster Mission</td>
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<td>4</td>
<td><strong>C/NOFS</strong> Communication/Navigation Outage Forecast System</td>
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<td>5</td>
<td><strong>FAST</strong> Fast Auroral Snapshot Explorer</td>
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<tr>
<td>6</td>
<td><strong>FGST</strong> Fermi Gamma Ray Space Telescope</td>
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<td>7</td>
<td><strong>GALEX</strong> Galaxy Evolution Explorer</td>
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<td>8</td>
<td><strong>GEOTAIL</strong> Geomagnetic Tail Laboratory.</td>
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<td>9</td>
<td><strong>INTEGRAL</strong> The INternational Gamma-Ray Astrophysics Laboratory</td>
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<tr>
<td>10</td>
<td><strong>RHESSI</strong> Ramaty High Energy Solar Spectroscopic Imager</td>
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<td>11</td>
<td><strong>RXTE</strong> Rossi X-Ray Timing Explorer (RXTE)</td>
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<tr>
<td>12</td>
<td><strong>SAMPEX</strong> Solar Anomalous Magnetospheric Particle Explorer</td>
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<td>13</td>
<td><strong>SOHO</strong> Solar Heliospheric Observatory (SOHO)</td>
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<td>14</td>
<td><strong>STEREO</strong> Solar TErrrestrial RElations Observatory</td>
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<td>15</td>
<td><strong>Swift</strong> The Swift Gamma-Ray Burst Mission</td>
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<tr>
<td>16</td>
<td><strong>THEMIS</strong> Time History of Events and Macroscale Interactions during Substorms</td>
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<tr>
<td>17</td>
<td><strong>TIMED</strong> Thermosphere, Ionosphere, Mesosphere, Energetics &amp; Dynamics Mission</td>
</tr>
<tr>
<td>18</td>
<td><strong>TRACE</strong> Transition Region and Coronal Explorer</td>
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<tr>
<td>19</td>
<td><strong>WIND</strong> Interplanetary Physics Laboratory</td>
</tr>
<tr>
<td>20</td>
<td><strong>WMAP</strong> Wilkinson Microwave Anisotropy Probe</td>
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### Earth Science Mission Operation (ESMO)

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<tr>
<td>1</td>
<td><strong>AURA</strong></td>
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<td>2</td>
<td><strong>LANDSAT-7</strong></td>
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<tr>
<td>3</td>
<td><strong>TERRA</strong></td>
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<tr>
<td>4</td>
<td><strong>AQUA</strong></td>
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<td>5</td>
<td><strong>Tropical Rainfall Measuring Mission (TRMM)</strong></td>
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<td>6</td>
<td><strong>Solar Radiation and Climate Experiment (SORCE)</strong></td>
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<tr>
<td>7</td>
<td><strong>GRACE</strong></td>
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<tr>
<td>8</td>
<td><strong>Ice, Cloud,and land Elevation Satellite (ICESaT)</strong></td>
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<td>9</td>
<td><strong>Earth Observing-1 (EO-1)</strong></td>
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<tr>
<td>10</td>
<td><strong>RHESSI</strong></td>
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</tbody>
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**Goddard Space Flight Center**

10/19/09 NASA Supply Chain Conference
Strategy for Implementation

- Establish and manage central database for Center missions anomaly reports, Spacecraft On-Orbit Anomaly Reporting Systems (SOARS)

- Integrate the mission operations assurance function into the flight team and communicating the project’s risks during the test and training exercises and the critical flight operations.

- Assess mission performance through policy, data analysis, compliance verification, validation, early intervention, and risk management.

- Capture and share lessons learned from investigation. Provide direct transfer of knowledge and experience to existing and Future Flight Projects.

- Provide the stakeholder feedback on cross-project critical anomaly issues and lessons learned.

- Ensuring the timely identification, criticality rating, assignment, failure risk rating and closure of anomalies identified in flight and during surface operations.
Strategy for Implementation

- Cross-mission anomaly avoidance and contingency planning
- Anomalies recorded in SOARS
- Deliver Complete Data & Lessons Learned from SOARS
- Near Real-time Anomalies Alerted
- Failure modes derived from real on-orbit performance
- Improve Mission Lives & Effectiveness
- Adequate Requirement Development
- S/C Developments
- S/C Designers
- Anomaly Management
- Reliability Analysis
- Mission Operations
Anomaly Management

- Sharing information of similar anomalies
- Coordinate with APL/LASP Mission Operation Team through GSFC Project Offices.
- Utilize SOARS database to support RTOP studies and other cases studied based on the lessons learned

JPL

APL/LASP

HQ
• FUSE - Mission lost all four reaction wheels

• GOES 9 - failures caused by lubrication starvation of momentum wheels.

• GPS BII-07 - 3-Axis stabilization failure due to a second reaction wheel failure

• HST - Fourth of six gyros fails

• IMAGE - Nutation damper liquid immobilized by surface tension

• Landsat 6 – Satellite exploded when propulsion system pyro-valve was fired, igniting adjacent mixture

• Mars Climate Orbiter - Failure to use metric units in ground software trajectory models

• Mars Observer - Propulsion System rupture or power short, induced by oxidizer leaking past check valves

• NEAR - Main engine fuel burn malfunction due to on-board software limits being exceeded

• TOMS-EP - Coarse Sun Sensors miswired; magnetic torque rod polarity
Design flaws and manufacturing defects have a greater effect on mission success than materials contamination or fatigue/overstress.

Testing should be done in as flight-like a configuration as possible (e.g. flight harnesses for polarity tests), and that all test results be understood.

An exception to the trend of anomalies occurring early in the mission is wheel anomalies suggests that mechanical wear-out is an increasingly significant factor. Investing in more robust life test programs for wheels can be beneficial.

Pyro-valves were also troublesome. Misuse has led to catastrophic damage of other components. The mechanical and electrical interactions of the pyro-valves with surrounding systems must be thoroughly understood.

Electronics Power Systems (EPS) problems associated with solar array and battery anomalies. Technical complexity and design lifetime for GEO communication satellites has increased the risk of failure in this subsystem.
• Automate as many functions as possible without risking the mission or breaking the budget. Automation is essential to the Science Operation Center (SOC) because it keeps down manpower costs by enabling fewer generalist operators to meet the majority of mission needs.

• Some examples of successfully implemented automation efforts include the following:
  – Automated Track Supports (ATS)6
  – Automated Telemetry Monitoring7
  – Automated Spacecraft Telemetry Trend Analysis
  – Automated Mission Planning
  – Automated Orbital Analysis8
  – Automated Remote Ground Stations

• Automation reduces human errors and improves mission success rates.
Case Study – Mishap of xyz Mission

- xyz satellite unexpectedly stopped all communications when failure to establish a routine communications contact with the Deep Space Network (DSN) occurred.

- Multiple attempts were made to reestablish communications, all of which have been unsuccessful.

- The cause of the failure was related to the Solid State Power Conversion (SSPC) that provides power service to both the Receiver and the Transmitter of the Transponder.
Case Study – Mishap of xyz Mission (cont.)

- **Loss Of Communications**

  - **SCU Failure**
  - **RF Component Failures**
  - **Transponder Failure**
  - **Equipment Short**
  - **Space Weather**
  - **Electrostatic Discharge**
  - **Debris Impact/Collision**
  - **Tin Whiskers**

  - **OTHER CAUSES**
    - **Operations**
      - **Stored commanding error**
      - **Misconfiguration of Watchdog Timer**
    - **Environment**
      - **DSN Misconfiguration**

  - **SPACECRAFT**
    - **PDU**
      - **SSPC Instant Trip**
      - **SSPC Failure**
      - **HLD Driver to Txpndr**
      - **PDU ESN/Processor**
      - **Charge Control Failure**
      - **GSE Relay Failure**
    - **Power**
      - **SA Failure**
      - **Battery Failure**
      - **Equipment Short**
    - **RF System**
      - **SCU Failure**
      - **RF Component Failures**
      - **Transponder Failure**

  - **GSE Relay Failure**

  - **SSPC Failure**
Case Study – Mishap of xyz Mission (cont.)

Fault Analysis – RF System

- Power Combiner/Splitter
- Diplexer
- Receiver/ Detector
- Transmitter
- RS 422 Data Interface
- System Control Unit (SCU)
- SSPC +28V Switched Service (single SSPC services both Rx and Tx)

Antenna System

RF Switching and Routing

Transponder

LGA 1 (Top of MGA)
LGA 2 (Z-)

OMNI

MGA

MGA (Z+)

50 Ohm Termination
Case Study – Mishap of xyz Mission (cont.)

• **Cause**: Simultaneous Transmitter/Receiver Failure.

• **Analysis**:
  – The transmitter and receiver sections of the transponder are functionally independent with separate power converters, although both power converters share the same power feed via an SSPC.
  – 20 critical functions of the transponder are identified in the FMEA. Failure of any one of those functions will kill either the transmitter or receiver, but not both.
  – The transponder has no history of anomalous behavior throughout its mission life in either the transmitter or receiver. All telemetry trend data has been analyzed and indicates nominal operation up to the last contact.
  – Transponder telemetry trend data and FMEA are available. The transponder has a reliable flight history. Eleven functionally similar transponders have successfully flown with no on-orbit failures or significant anomalies.
  – In addition, it has flown on at least 8 other missions also with no on-orbit failures or significant anomalies.
Lesson #1:
The Transponder Receiver should have had redundancy built into its power switching or the sensed operational status – even if the mission is designed as single string throughout. Hardwiring the receiver power is typical Industry wide practice.

Lesson #2:
Part anomaly alert process should be more inclusive to operations personnel.

Lesson #3:
Complete & accurate as-built design documentation is essential for anomaly resolution.

Lesson #4:
Safing limits & operational procedures related to battery SOC should be adjusted to account for battery degradation as the mission progresses past the nominal lifetime.
Conclusions

- Data survey was that industry-wide data is not shared on a routine basis. It is difficult to learn from history if anomaly records are kept out of the public domain.

- The standard spacecraft integration and test process already invests significant effort to expose design flaws and physical defects before launch.

- Is more testing needed? Not necessarily; a correlation between parts failures and stress due to excessive testing.

- Suppliers should coordinate with the NASA lessons learned systems to take advantage of the latest and best information.

- Design the missions with the flexibility and built-in processes to recognize problems or anomalies, analyze them, and provide a feedback loop to introduce improvements back into the mission operations process.

- Investing early in a comprehensive science and mission operations concept will yield a substantial pay-off in development and operations phases of a mission.

- Valuable lessons are learned from the flight and post-flight analyses, which will be reflected in the design of future spacecraft.