On-Orbit Anomaly Management and Lessons Learned

Jim La

Supply Chain 2009 Conference
October 15, 2009

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.

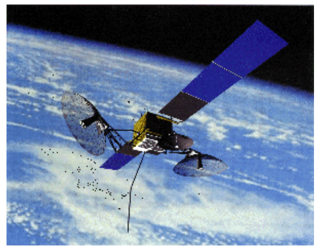
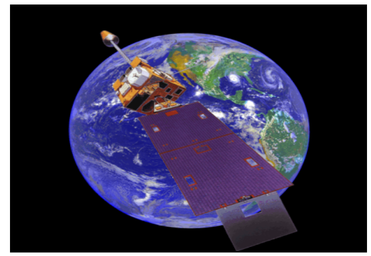
- Analysis on-orbit experiences provide the basis for effective strategist & paradigms

- 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

Goddard Space Flight Center

HST	TDRS	GOES	POES
			

Space Science Mission Operation (SSMO)

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

Earth Science Mission Operation (ESMO)

1. AURA
2. LANDSAT-7
3. TERRA
4. AQUA
5. Tropical Rainfall Measuring
6. Mission (TRMM)
7. Solar Radiation and Climate Experiment (SORCE)
8. GRACE
9. Ice, Cloud,and land Elevation Satellite (ICESaT)
10. Earth Observing-1 (EO-1)

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.

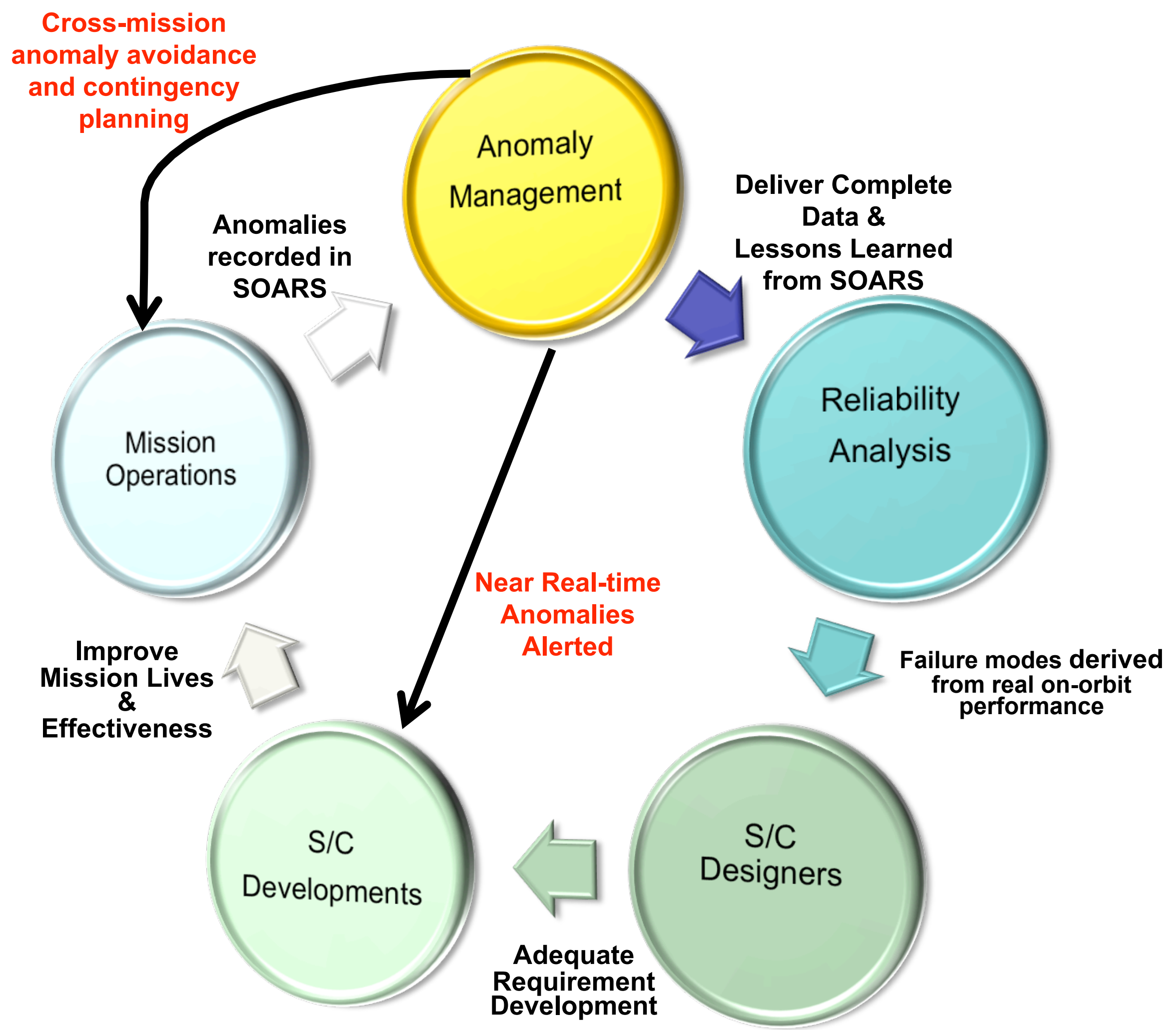
- Capture and share lessons learned from investigation. Provide direct transfer of knowledge and experience to existing and Future Flight Projects.

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

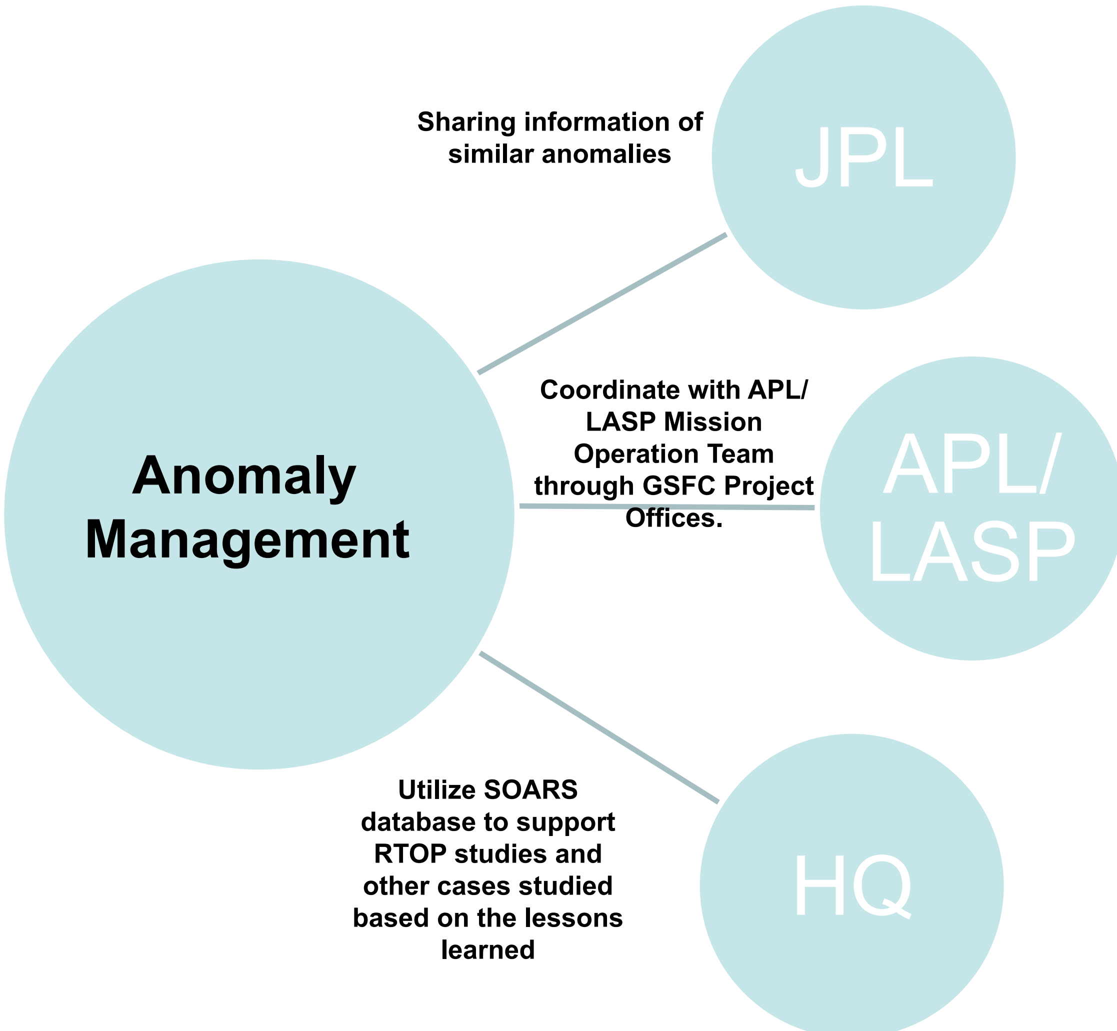
- Ensuring the timely identification, criticality rating, assignment, failure risk rating and closure of anomalies identified in flight and during surface operations.

Goddard Space Flight Center

Strategy for Implementation



Collaboration with others



On-Orbit Anomaly/Supply Chain

- **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

On-Orbit Anomaly /Supply Chain

- 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.

Automation

- 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.

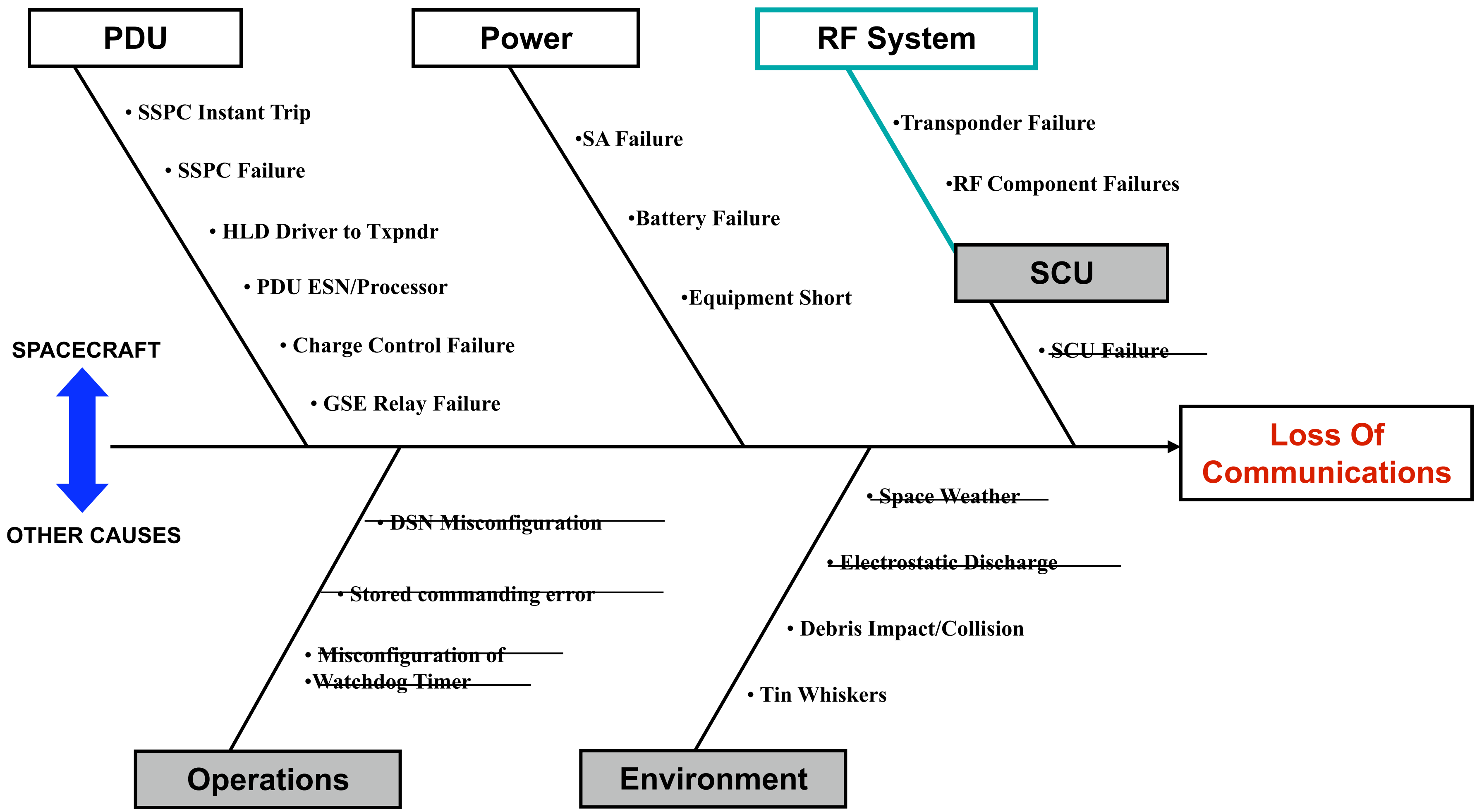
- Some examples of successfully implemented automation efforts include the following:
  - Automated Track Supports (ATS)6
  - Automated Telemetry Monitoring7
  - Automated Spacecraft Telemetry Trend Analysis
  - Automated Mission Planning
  - Automated Orbital Analysis8
  - Automated Remote Ground Stations

- Automation reduces human errors and improves mission success rates.

Case Study – Mishap of xyz Mission

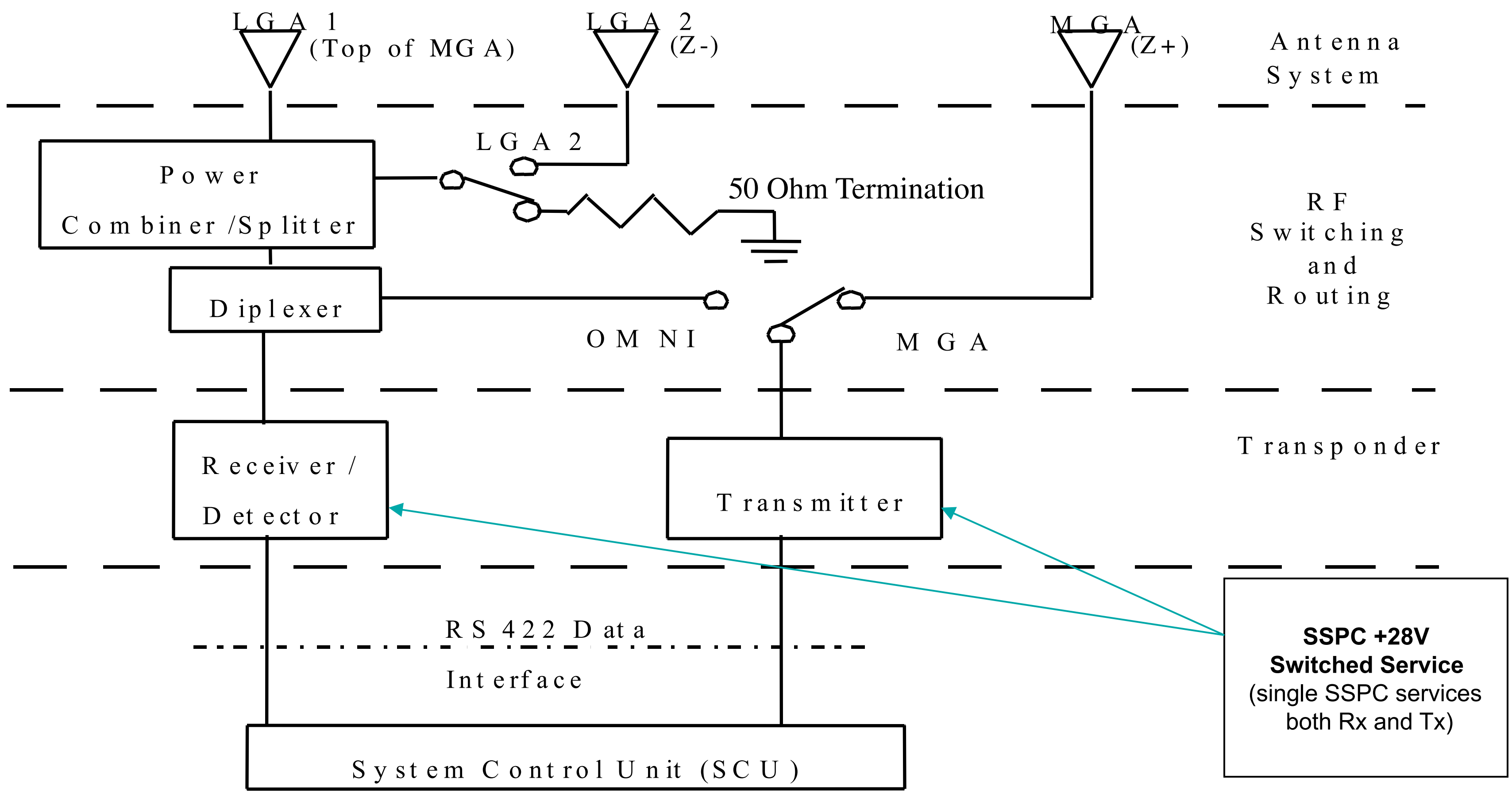
- xyz satellite unexpectedly stopped all communications when failure to establish a routine communications contact with the Deep Space Network (DSN) occurred.
- Multiple attempts were made to reestablish communications, all of which have been unsuccessful.
- The cause of the failure was related to the 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.)



Case Study – Mishap of xyz Mission (cont.)

Fault Analysis – RF System



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.

Case Study – Mishap of xyz Mission (cont.)

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.