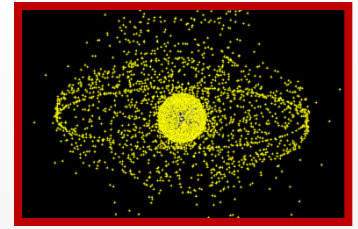
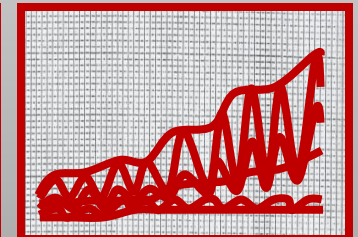
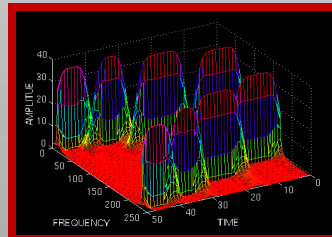
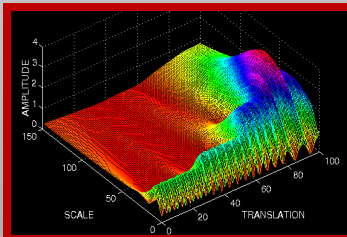
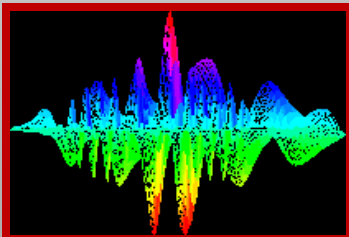


FA Failure Analysis



Oracol[®]

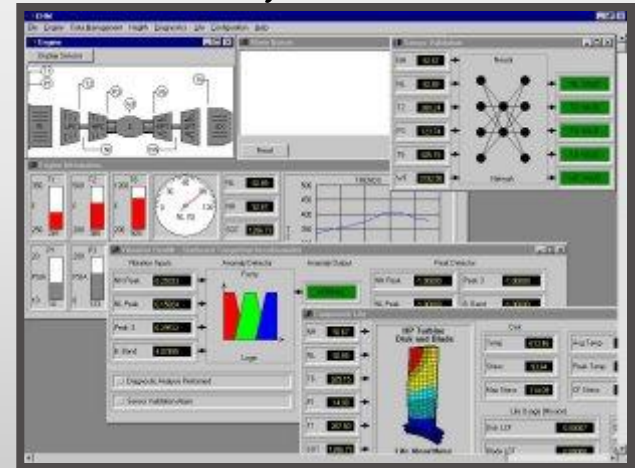
**Making Working in Space Safe by
Predicting On-Orbit Spacecraft and
Satellite Equipment Analog Behavior
Accurately**



Making Working in Space Safe by Predicting On-Orbit Spacecraft and Satellite Equipment Analog Behavior Accurately

- **Problem: Working in Space is Unsafe**

- Oracol[®] Provides Normal, On-Orbit Satellite Equipment Telemetry Measurement Behavior Predictions Prior to Launch
 - Available Months Prior to and/or after Launch
 - Suitable for all planetary satellites/altitudes/inclinations/attitude control /thermal control electrical power configurations and equipment
 - Unlimited duration of predictions (30+ years)
 - Used by the Mission Control Team to define normal satellite equipment behavior
 - Decreases risk of mission failure
 - Identify suspect equipment problems in advance
 - Increases depth of understanding of Satellite on-behavior
 - Increases technical ability of Mission Control team personnel to quantify satellite equipment behavior

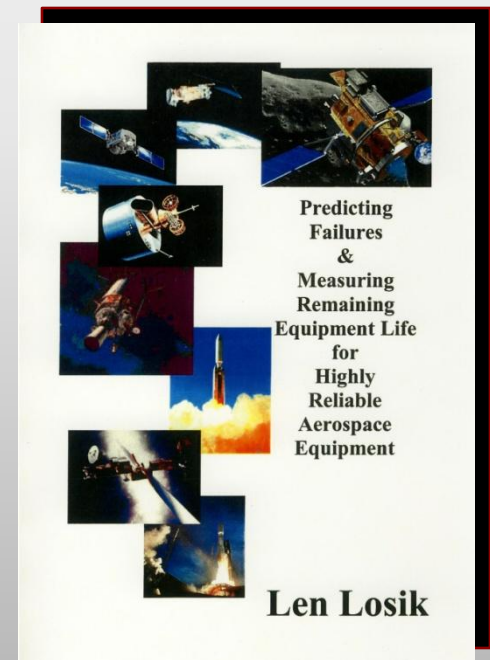


Commercially Available
Telemetry Behavior Prediction
Software Display Page

Making Working in Space Safe by Predicting On-Orbit Spacecraft and Satellite Equipment Analog Behavior Accurately

- **Oracol[®] Uses Telemetry Prognostic Algorithms for Predicting Fixed-Power Spacecraft Equipment Failures**

- To identify equipment that is going to fail, normal telemetry behavior has to be identified
 - Model-based prognostic algorithms
 - Experts create and supply normal behavior a-prior
 - Data-driven prognostic algorithms
 - Normal behavior is created near real-time using available telemetry behavior
 - Independent of source
 - Requires no a-priori knowledge
 - Insensitive to location, data quality and amount of data



**Available from
Amazon.com**

Making Working in Space Safe by Predicting On-Orbit Spacecraft and Satellite Equipment Analog Behavior Accurately

• Benefits from Predicting Telemetry Behavior

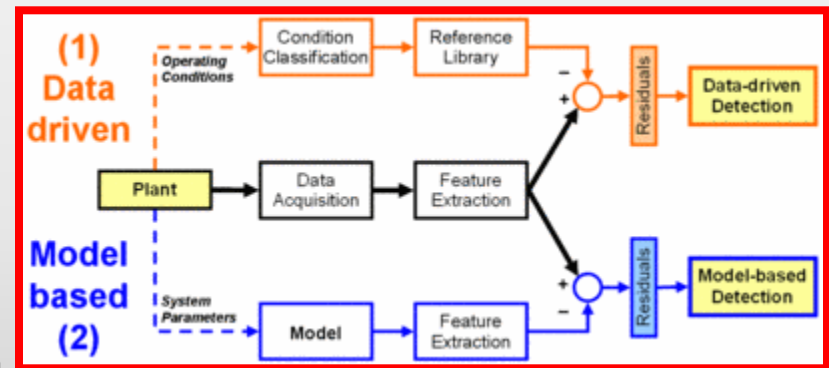
- Lowers risk of mission failure
 - Reduces surprise equipment failures
 - Most failures occur well within limits
 - Provides a heads-up warning that something has changed the expected behavior
 - Allows sufficient time for mission control team to respond/develop contingency procedure

• Increases depth of mission control team

- Provide the information necessary for the mission control team to understand what should be occurring on a satellite

• Can be a training tool for mission control

- Mission control team has limited information regarding the long term behavior of satellite from builder



Data-Driven and Model-Based Algorithms Use

Making Working in Space Safe by Predicting On-Orbit Spacecraft and Satellite Equipment Analog Behavior Accurately

- **Example of the Failure of the \$150M SUPERBIRD C & Ku-Band Geostationary Communications Satellite**

- Total loss from failure by satellite engineers to identify change in normal satellite telemetry after an ESD that caused a loss of earth-lock
 - Oxidizer leaked from an unidentified open isolation valve for 3 days
 - Satellite telemetry Indicated drop In oxidizer tank pressure, change not detected
 - Normal oxidizer tank pressure telemetry behavior unavailable for comparison



SCC SUPERBIRD B

9/12/2010

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- **\$65M GPS NAVSTAR 5 Failed Due to Failure to Identify Accelerated Aging in Reaction wheel Telemetry Behavior**
 - 2 out of 4 reaction wheels spin rate decreased to 0 rpm and froze at 0 rpm over 30 day period
 - Reaction wheel telemetry behavior well within normal operating range when reaction wheel failure occurred
 - If telemetry behavior was identified using reference reaction wheel failure could have been reversed

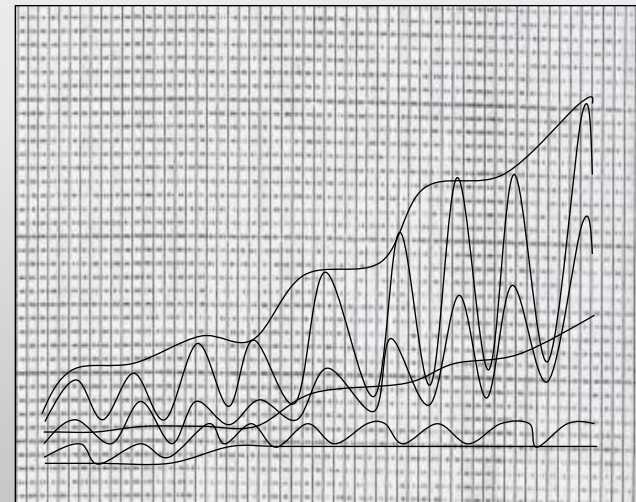


Boeing GPS NAVSTAR 5 Satellite Failed On-Orbit while Being Monitored by Engineering

Making Working in Space Safe by Predicting On-Orbit Spacecraft and Satellite Equipment Analog Behavior Accurately

- **Fixed-Power Behavior Predictions Include All Common On-Orbit Satellite Activities Including:**

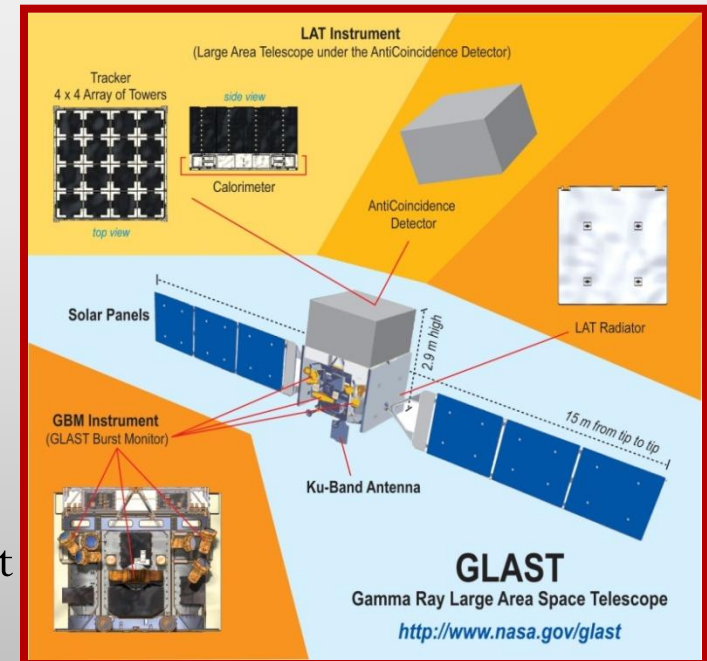
- Equipment cycling
 - TT&C
 - Gyros
 - Payloads
- Eclipse season
- Battery Reconditioning
- Station-keeping ΔV , Re-phasing ΔV
- Reorientations
- Loss of Earth-Lock, Loss of Sun-Lock
- Earth/Sun Re-acquisitions
- Noon-turns
- On-orbit Storage



Min / Max / Average
Daily / Weekly / Monthly Peaks Long
Term Telemetry Behavior Prediction

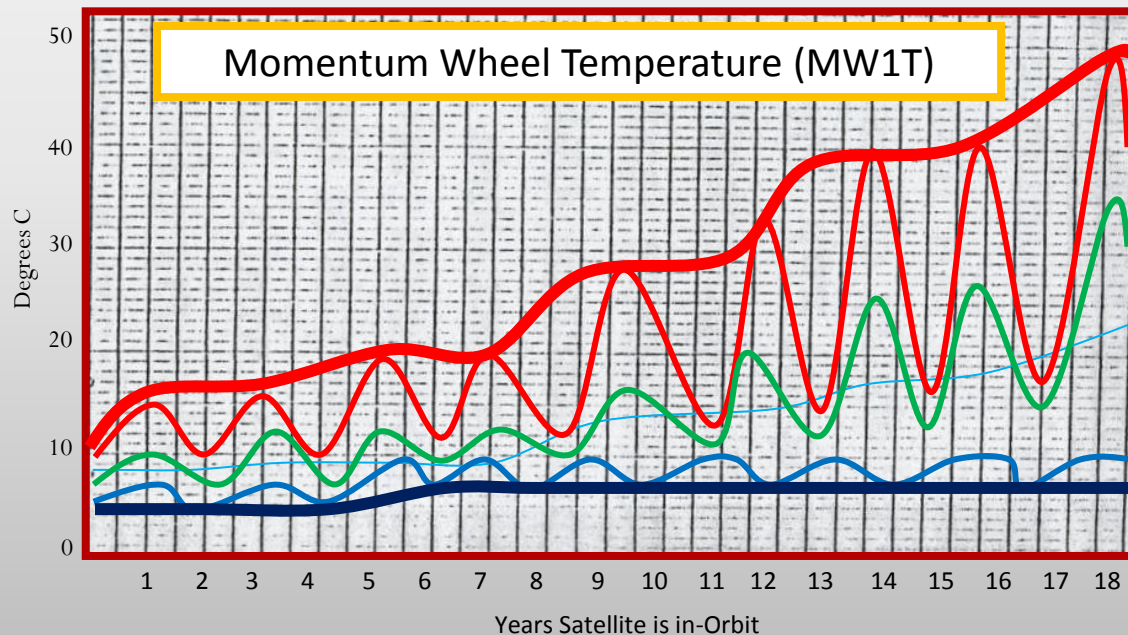
Making Working in Space Safe by Predicting On-Orbit Spacecraft and Satellite Equipment Analog Behavior Accurately

- **Information Needed to Predict Telemetry Behavior:**
 - 3-dimensional diagram of satellite with equipment locations identified by size and axis
 - For nadir pointing satellites, solar aspect angle around orbit
 - East/west/earth/anti-earth/north/south panel thermal blanket α (emissivity/absorptivity) for the duration of predictions desired
 - Access to all thermal vacuum test data and satellite equipment configuration information for equipment from thermal vacuum testing
 - On-orbit satellite equipment list to be powered on at start of predictions (beginning of mission life)
- High level satellite equipment physical and mechanical location diagrams



Making Working in Space Safe by Predicting On-Orbit Spacecraft and Satellite Equipment Analog Behavior Accurately

- An Example of Oracol[®] 2-D Standard Output



Peak values envelope – Red

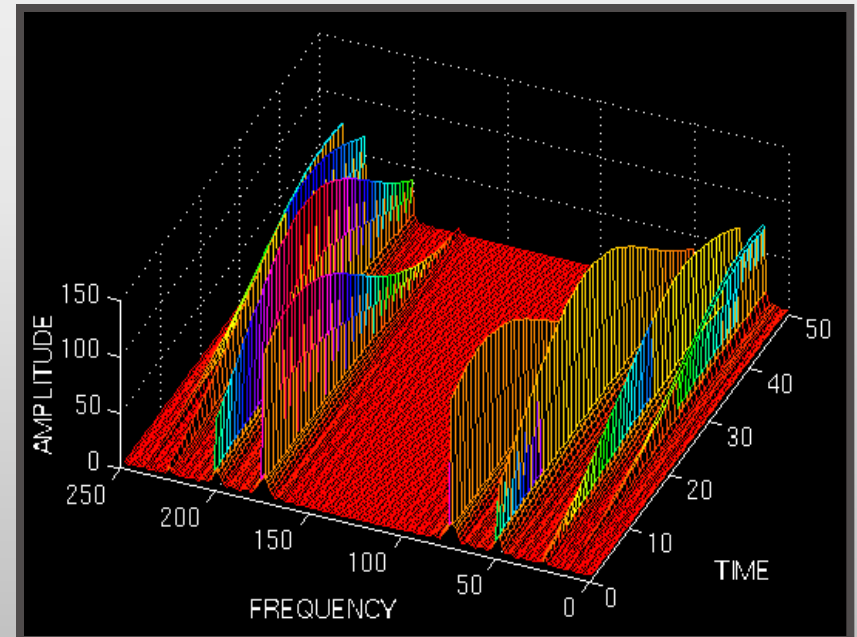
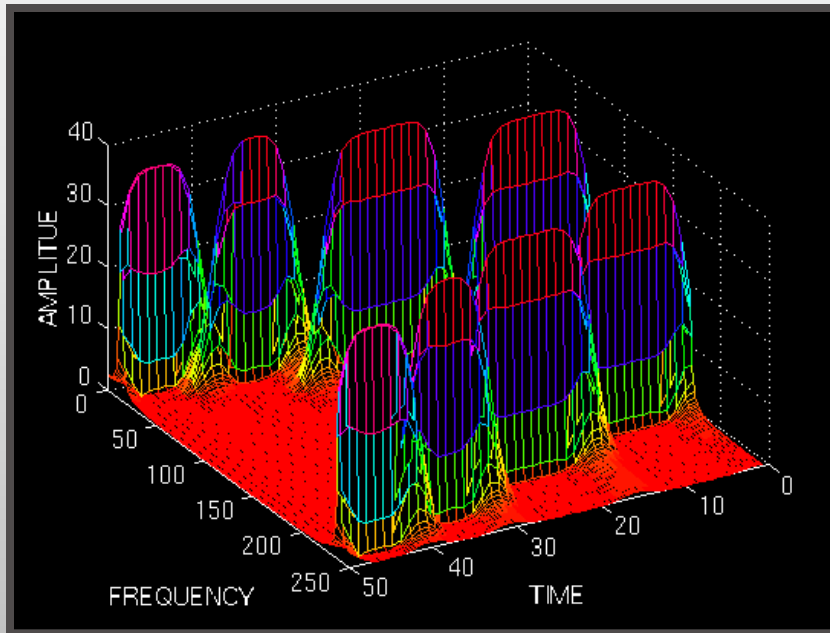
Minimum values envelope – Green

Average values of the envelope – Blue

Minimum/average/maximum values - Black

Making Working in Space Safe by Predicting On-Orbit Spacecraft and Satellite Equipment Analog Behavior Accurately

- 4-Dimensional Formats For Identifying Missing Data



Making Working in Space Safe by Predicting On-Orbit Spacecraft and Satellite Equipment Analog Behavior Accurately

- **Conclusion**

- Satellites fail catastrophically from fixed-power equipment failures that behave well within normal and thus often overlooked
- Telemetry is critical to the safety of space vehicles operating in space
- Satellite and spacecraft equipment telemetry behavior is harmonic and can be quantified using harmonic analysis
- Prognostic algorithms used to generate normal telemetry behavior in factory ATP can be adapted for predicting normal on-orbit equipment telemetry behavior from planetary satellites
- Engineers will compare predicted with actual behavior and identify equipment that is in the process of failing and avert catastrophic losses



FAILURE ANALYSIS

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