CYGNSS Spacecraft Component and Subsystem Reliability Lessons Learned

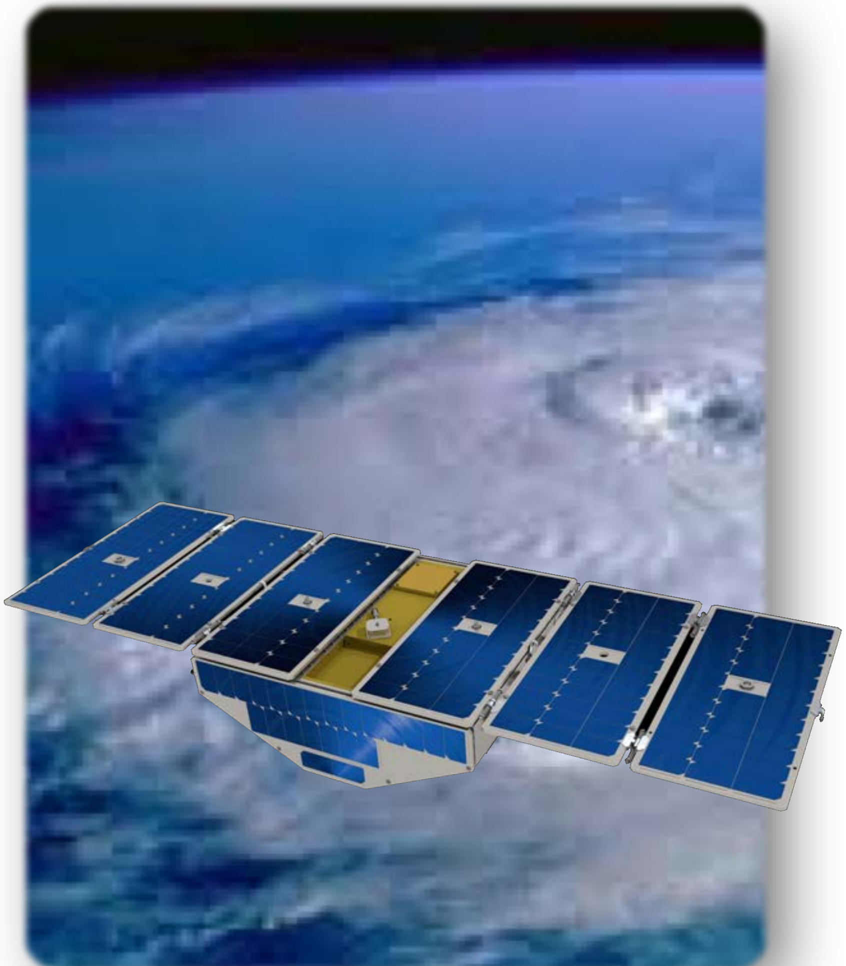
- *NASA SmallSat Reliability TIM* -

Randy Rose
CYGNSS Project Systems Engineer
Southwest Research Institute
rrose@swri.org/303.588.2157

TIM Charter

- *Define implementable and broadly accepted approaches to achieve reliability and acceptable risk postures associated with several SmallSat mission risk classes—from "do no harm" missions, to missions whose failure would result in loss or delay of key national objectives. These approaches will maintain, to the extent practical, cost efficiencies associated with small satellite missions and consider supply chain elements constraints, as appropriate.*
- *Address this challenge from two architectural scopes—the mission- and system-level, and the component- and subsystem-level. The mission- and system-level scope targets assessment approaches that are efficient and effective, and mitigation strategies that facilitate resiliency to mission or system anomalies while the component- and subsystem-level scope addresses the challenge at lower architectural levels.*

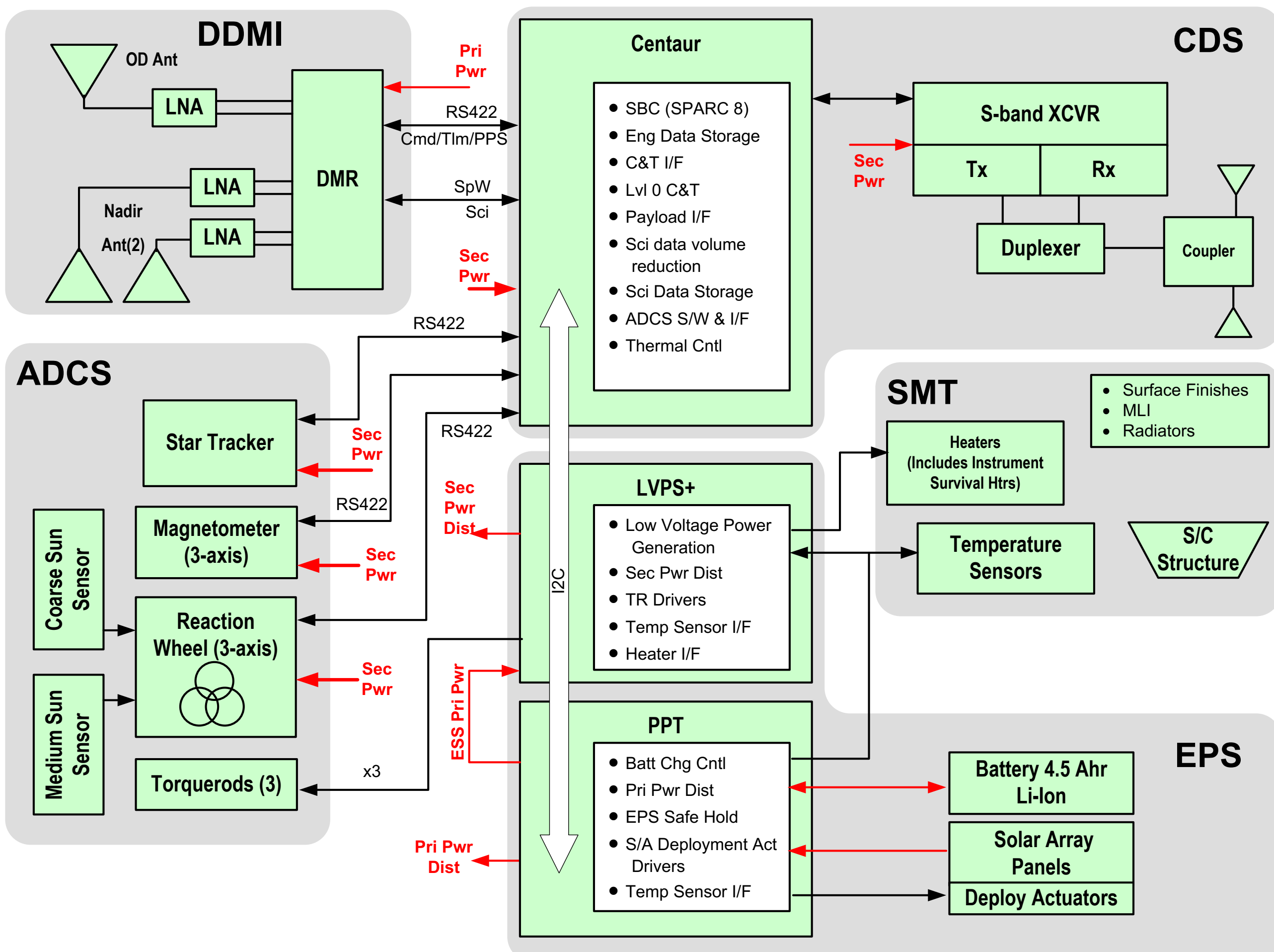
CYGNSS Observatory Key Characteristics



- Power: 38.3 W
  - Available: 70 W EOL
    - (as configured for CYGNSS)
  - Margin: 23%
- Pointing
  - Star tracker based 3-axis reaction wheel stabilized
    - 30 arc-sec (3σ) attitude knowledge
    - 0.2 deg (3σ) attitude control
  - Full momentum management without payload duty cycle interruption
  - Capable of nadir, LVLH, or inertial pointing
- Mass: 24.8 kg

Observatory Functional Block Diagram

- Single String Architecture
- Instrument driven configuration
- ST-based 3-axis RW attitude control
- Fixed panel, deployed Solar Array
- S-Band CCSDS Comm
- Highly Integrated Structure



Spacecraft-Level Reliability Philosophy

- Low-cost, Class D mission
  - CubeSat-class components necessary to enable mission implementation
  - CYGNSS operates in LEO with inclination subject to SAA
- Maximize fault tolerance by eliminating unnecessary failure points
  - Redundancy is achieved at the constellation
  - Observatories in the constellation are independent of each other
  - The CYGNSS orbit is stable; there are no time-critical maneuvers required
- Do the minimum necessary to keep the Observatory safe
  - Complex fault response functionality adds failure points
- Fault management…
  - Encompasses the entire Observatory
  - Addresses only known fault conditions

Subsystem-Level Fault Tolerance Strategies

- Use of select single fault tolerance
  - Dual Observatory separation actuator drives and initiators
  - Dual solar array actuator electrical drives and initiators
  - Reaction wheels functional redundancy
- Segregated functionality
  - Robust Safe Mode using a Sun pointing attitude configuration using minimal sensors and effectors during Safe mode
  - Loss of communication time-out
  - Level 0 hardware based command and telemetry
  - Hardware based Transmitter power on time-out
  - Independent processor watch dog timer
  - Hardware only battery charging circuit
  - Independent hardware-only survival heaters

Fault Management Lessons Learned

- In order to efficiently fly a constellation of 8 s/c, autonomous on-board fault detection and management is a necessity
  - CYGNSS treated fault management as a subsystem
- Significant learning curve during both ground and on-orbit operations to understanding the autonomous fault handling requirements, development of the procedures, and testing and troubleshooting of the implementation
  - Ability to modify fault thresholds & responses key in working through issues of “component youth”

Lessons Learned from a Multiple Spacecraft Perspective

- "Identical" spacecraft and subsystems aren't, they will have their own personality quirks
  - Plan for these differences in mission operations processes & procedures, on-board fault management, on-board parameter structures, etc.
- Use parametric analysis of areas of performance sensitive to minor variances between spacecraft
  - Significant analysis is went into this on CYGNSS, but spacecraft-specific issues can "sneak" into unexpected places
  - Carry robust power margins at launch to address "unknown unknowns"

Reliability at the Part Level

- Successful operations beyond short-term demo's require EEE part level engineering
  - Layered part quality acceptability
  - Lead-free manufacturing
  - Plastic Encapsulated Devices
  - Radiation susceptibility
- Implementation of the EEE parts plan required active involvement of risk mitigation strategies and management