BioSentinel

Mission Development of a Radiation Biosensor to Gauge DNA Damage and Repair Beyond Low Earth Orbit on a 6U Nanosatellite

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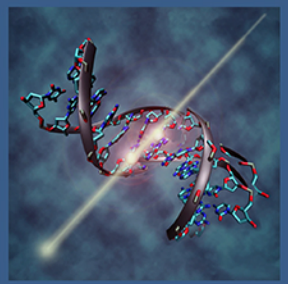
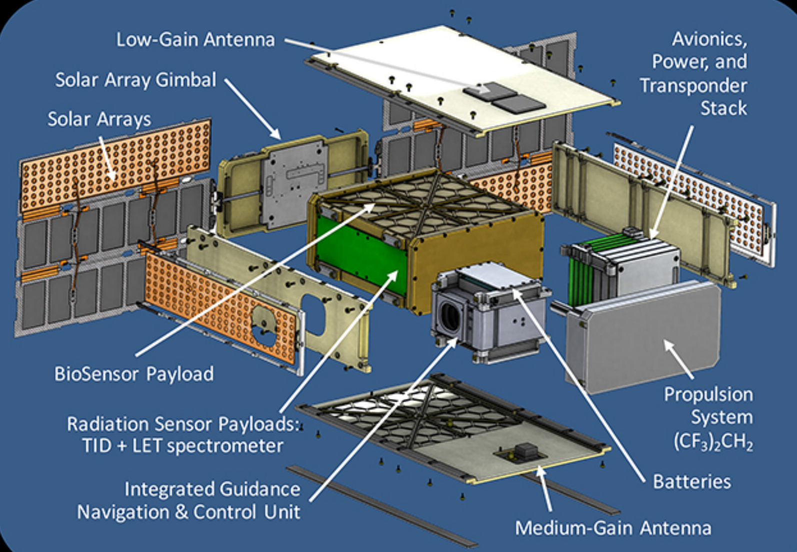
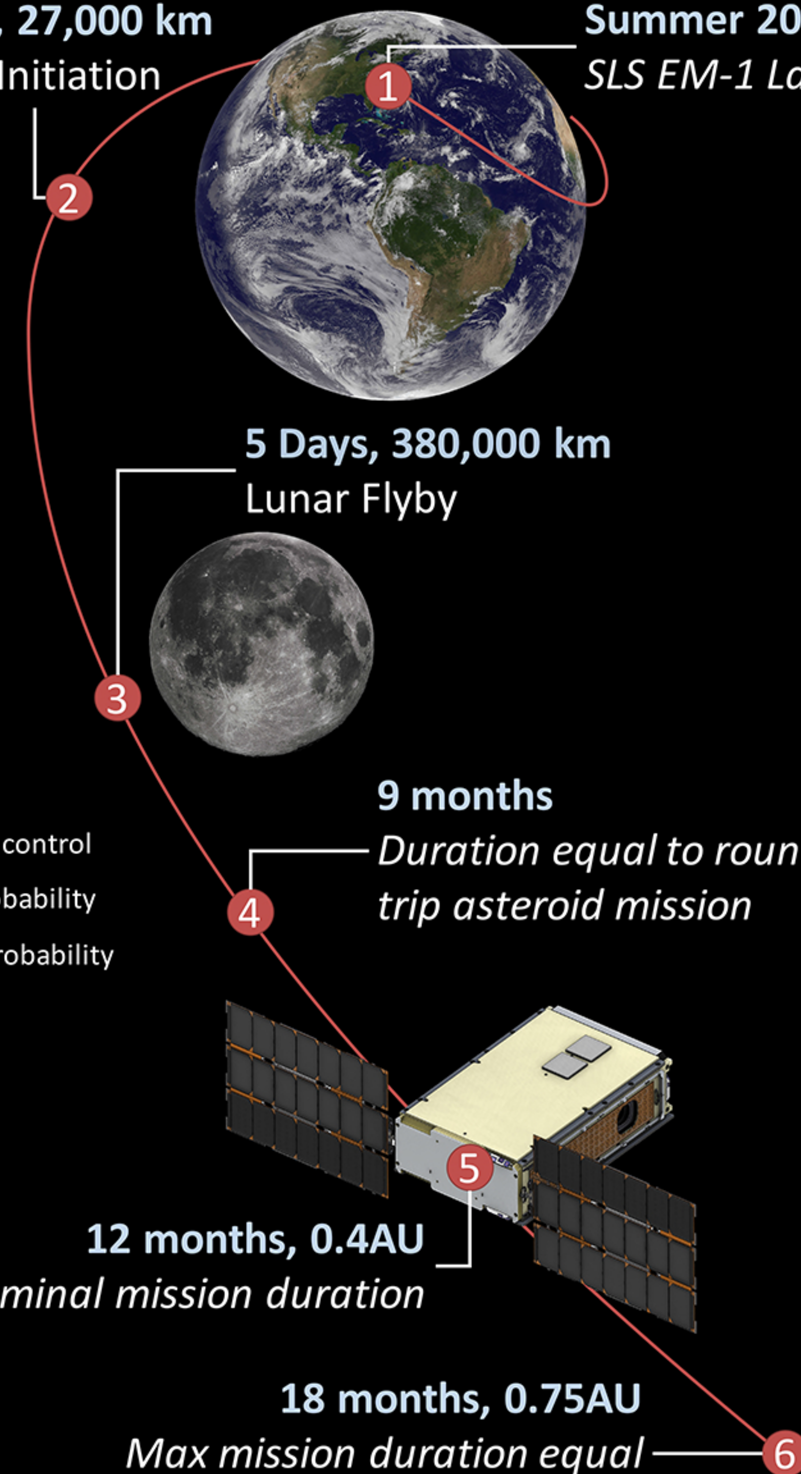
BioSentinel Mission: "Canary in a Coal Mine"



- ***Quantify DNA damage from space radiation environment***
  - Space environment cannot be reproduced on Earth: *omnidirectional, continuous, low flux, variety of particle types*
  - Health risk for humans spending long durations beyond low Earth orbit (LEO)
  - Radiation flux can spike 1000x during a solar particle event (SPE)
- **Yeast assay: microfluidic arrays monitor DSB/repair**
  - Three strains of *S. cerevisae*: 2 controls, 1 engineered strain
    - Engineered strain quantifies double strand breaks (DSBs)
  - Wet and activate multiple banks of microwells over mission lifetime
  - Double strand break & associated repair enable cell growth & division
  - Reserve wells activated autonomously in case of SPE
- **Correlate biological response with physical radiation measurements**
  - ***Total Ionizing Dose*** (TID) sensor measures integrated deposited energy
  - ***Linear Energy Transfer*** (LET) spectrometer bins and counts particle events



6 U volume
14 kg mass
30 watts power
3 science payloads
18 Biosensor fluidics cards
Cold gas thruster system
3 degree of freedom attitude control
0.65 krad-Si, mean dose probability
1.3 krad-Si, 95% max dose probability

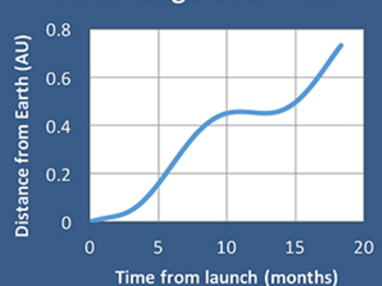


Spacecraft Design: 6U Cubesat

- A "6U" (10 x 22 x 34 cm) nanosatellite
- First NASA biological study beyond LEO in over forty years (since Apollo)
- Results will be compared to data obtained in LEO (on International Space Station) and on Earth
- Active attitude control required for RF communication and solar power generation

Concept of Operations: Deep Space

Earth Range Over Time



- Secondary payload aboard Space Launch System (SLS) Exploration Mission-1 (EM-1)
- Launch from Kennedy Space Center (KSC)
- 12- to 18-month mission lifetime
- Earth-leading ~0.93 – 0.98 AU heliocentric orbit
- Total ionizing dose with 1.85 mm of aluminum shielding (0.5 g/cm2) over 1 year:
  - 0.65 krad in silicon, mean dose probability
  - 1.3 krad in silicon, 95% maximum dose probability (important for EEE parts selection)

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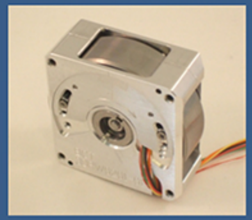
Fault Modes Definition: FMECA



- Performed spacecraft level Failure Modes, Effects, and Criticality Analysis (FMECA)
  - Example of tables/process below
  - Example case is for a reaction wheel failure (RW pictured on right)
- FMECA identified how each item would be addressed: flight software function, mission operations procedure, design update, minimum risk design approach, or a combination of these.

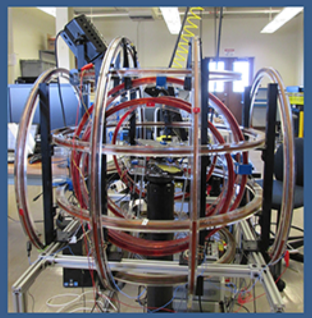
Failure Mode Number	Item or Function	Failure Source a. Failure Mode b. Failure cause	Failure Effects a. Local b. System c. Mission	Consequence Level	Remarks a. Detection Method b. Compensating Features c. Other	Fault Mode Responses
Example 1	No Comm with Ground	a. No ground commands b. RW speed saturation	a. RW limited b. Increasing rates c. No new commands	4	a. IMU rate data b. Vendor testing c. Rate reduction tested during checkout	High speed activates propulsion
Example 2	No Comm with Ground	a. No ground commands b. ADCS overload	a. No RW response b. Increasing rates c. No comm	5	a. Current sensors b. Vendor testing c. Rate reduction tested during checkout	High current limit turns off wheels

Fault Mitigation: Detection and Response

- Fault Management Plan defines items addressed by flight software
  - Core Flight Services (cFS) Limit Checker Module used for implementation
  - Watch Points (WPs) use on-board telemetry source (mnemonic)
    - Watch Points mapped to software applications
    - Added mnemonics to Interface Control Documents (ICDs)
    - Identified thresholds and persistence for action
  - Action Points (APs) built based on Boolean states of WP
    - Allows different thresholds based on operating modes
  - Added WPs and APs based on review of LADEE mission fault plan and
  - Added WPs and APs based on review with payload, mission operations, and spacecraft teams

WP#	Description	Software Module	Comparison Value
8	Reaction Wheel 1 current sensor	EPS IO	>500 mA
41	Reaction Wheel 1 Soft Speed Limit	ACS IO	>2000 rpm
44	Reaction Wheel 1 Hard Speed Limit	ACS IO	>4500 rpm

Verification: Testbeds



- Electrical Power System (EPS) Engineering Development Unit (EDU) hardware
  - Used to replicate over current and verify response
- Generalized Nanosatellite Avionics Testbed (G-NAT)
  - Testing data and general test protocols for sensors, actuators, and processors
  - An air bearing allows for three degrees-of-freedom (3-DOF) rotational motion within a Helmholtz cage
  - "Attitude truth" resolved from a set of infrared LEDs being tracked using a COTS digital camera.

Summary

- BioSentinel is deep space cubesat mission that will require autonomous 3-DOF attitude control in a high radiation deep space environment
- 35 failure modes identified in FMECA with 35 possible implementations of mitigations in flight software
- Action Points table developed with Boolean logic for watch point combinations