Reliability Analysis and Risk Management of SwampSat

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Introduction

- Design and development of nano- and pico-satellites have become extremely popular in recent years
- Popularity are buoyed by shorter development time and lower cost (launch and satellite) especially to first time satellite developers
- These factors lead to use of "off-the-shelf" components
- Lack of components with flight heritage results in need for reliability analysis to reduce potential risks
  - Perform reliability analysis to identify possible failure modes and high risk components
  - With identification of possible failure modes and high risk components, mitigation plans and strategies must be developed to reduce risks

<u>Reliability Analysis</u>

- Performed to identify and mitigate failures that affect the operational capability of a system under given conditions
- Two most common techniques
  - Failure Modes, Effects, and Criticality Analysis (FMECA)
  - Fault Tree Analysis (FTA)

Reliability Analysis

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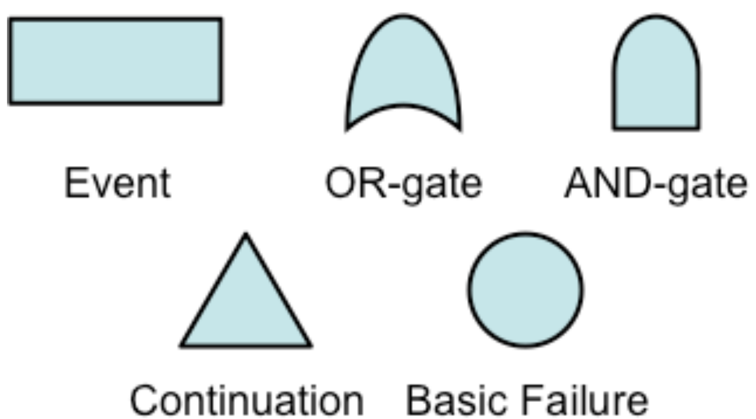
Failure Modes, Effects, and Criticality Analysis (FMECA)

- For each failure mode:
  - Potential cause of failure
  - Effects are evaluated at the next system level
  - Criticality is calculated based on severity and likelihood of occurrence (Risk Matrix)
  - Method of detection
  - Potential mitigation plan

Likelihood	Severity 1	Severity 2	Severity 3	Severity 4	Severity 5
5	(Low)	(Mod)	(High)	(High)	(High)
4	(Low)	(Mod)	(Mod)	(High)	(High)
3	(Low)	(Low)	(Mod)	(Mod)	(High)
2	(Low)	(Low)	(Low)	(Mod)	(Mod)
1	(Low)	(Low)	(Low)	(Low)	(Mod)

Fault Tree Analysis (FTA)

- Complements the FMECA by starting with a top-level failure effect and traces the failure to lower potential causes
- Fault tree constructed using FTA symbols, also known as logic gates



SwampSat

- SwampSat is a 1U CubeSat developed by the Space Systems Group at the University of Florida
- SwampSat's mission is an on-orbit validation of a compact, three-axis attitude actuator capable of rapid retargeting and precision pointing (R2P2) using four control moment gyroscopes (CMG) in a pyramidal configuration
- Successful completion of the SwampSat mission provides flight heritage to the CMGs (known as *IMPAC 2.0*)

Reliability Analysis: SwampSat FMECA

- FMECA was constructed in a tabular form

Hypothetical Failure Mode	Hypothetical Failure Cause	Hypothetical Potential Effects	Severity (1-5)	Likelihood (1-5)	Criticality	Detection Method	Preventative Action
IMU ADIS16405 Failure	IMU temperature sensor failure	Unable to downlink temperature data of IMU	1	2	2	Unable to obtain IMU temperature data from SwampSat	Functionality testing before launch
	SPI signal error	CMG controller unable to read IMU data	5	2	10	No IMU data from SwampSat downlink	Functionality testing and run software during testing to ensure algorithm is working properly
	IMU breaks due to environmental conditions (thermal and vibrations)	Unable to take IMU measurements	5	2	10	No IMU data from SwampSat downlink	Environmental (thermal and vibration) testing before launch
Magnet Coils Failure	PCB panels failure due to environmental conditions	Unable to use magnet coils, no power generation from solar cells	5	2	10	No communication from SwampSat	Environmental (thermal and vibration) testing before launch
	Malfunction of the load switch	Unable to generate magnetic field to interact with the Earth's magnetic field	5	2	10	IMU rates are high and the Flag = Failure	Functionality testing before launch
	Insufficient magnetic field generation	Unable to detumble due to weak magnetic field generation from magnetic coils	5	2	10	IMU rates are high and the Flag = Failure repetitively	Functionality testing, simulation, and analysis before launch
Software Error in Detumble algorithm	Programming error	Unable to operate Detumble mode, Detumble Failure	5	4	20	No detumbling information in downlink from SwampSat	Run software during testing to ensure algorithm is working properly

Reliability Analysis: SwampSat FTA

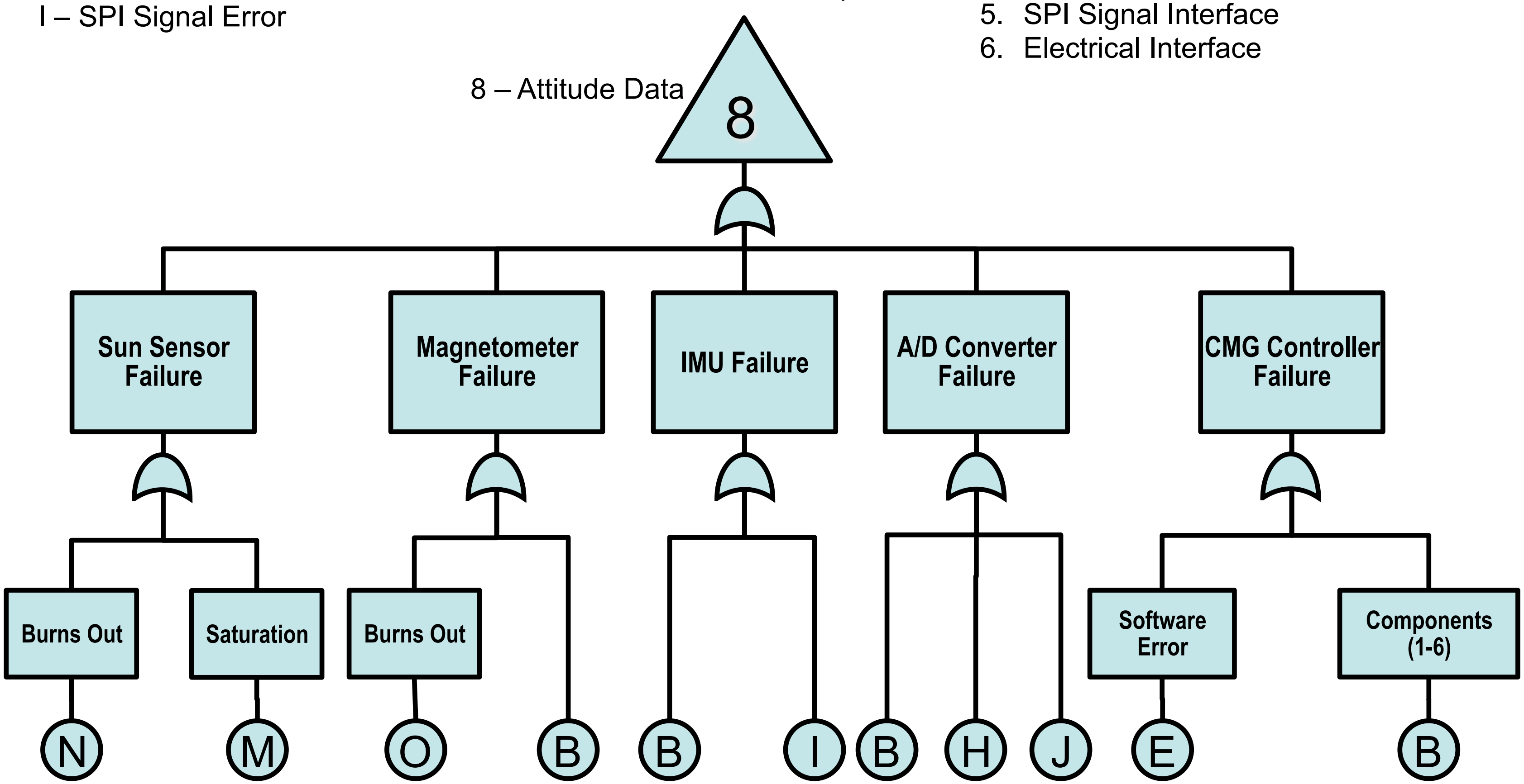
- FTA was constructed using failure modes from FMECA as top-level events

<u>Basic Failure Events:</u>

B – Breaks due to Environmental Conditions (Thermal and Vibrations)
E – Programming Error
H – I2C Signal Error
I – SPI Signal Error
J – ADC signal Error
M – Filter Failure
N – Radiation Damage
O – Power Bus Spike

<u>CMG Controller Components:</u>

1. Flywheel Motor Control Board
2. Gimbal Motor Control Board
3. CMG Control Software and Steering Logic
4. Flash Storage
5. SPI Signal Interface
6. Electrical Interface



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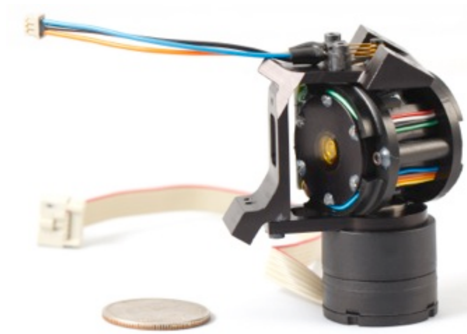
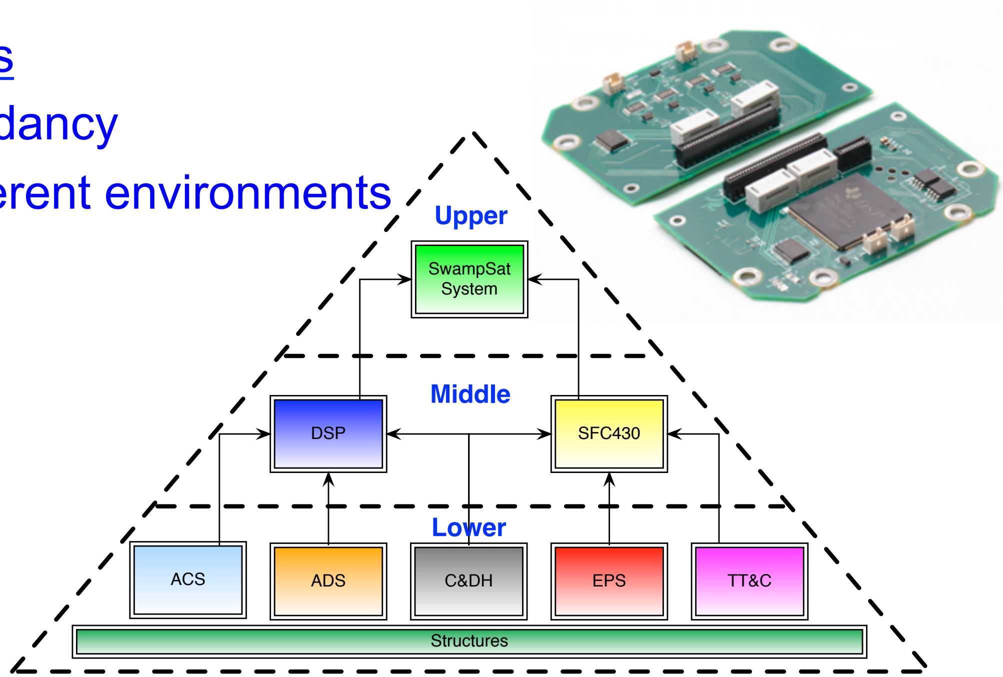
Risk Management for SwampSat

- SwampSat's reliability analysis resulted in all "built in-house" components identified as high risk
  - CMGs
  - Flight computer board
  - Motor controller board
  - Software



<u>Mitigation Plans and Strategies</u>

1. Robustness and redundancy
2. Rigorous testing in different environments
   - Component level
   - Subsystem level
   - Subassembly level
   - System level



Risk Management for SwampSat

Robustness and Redundancy

High Risk Items	Key Characteristics
CMGs	• 4 CMGs • Each individual CMGs or the entire pyramid configuration can be isolated from other subsystems
Flight Computer Board	• 4 EEPROMs • Three-axis Gyroscope • Three-axis Magnetometer • Multiple Temperature Sensors
Motor Controller Board	• 2 EEPROMs • Three-axis IMU with Gyroscope, Magnetometer, and Accelerometer • Multiple Temperature Sensors
Software	• Designed and developed to adapt to potential failures • Parameters can be modified via uplink from ground station

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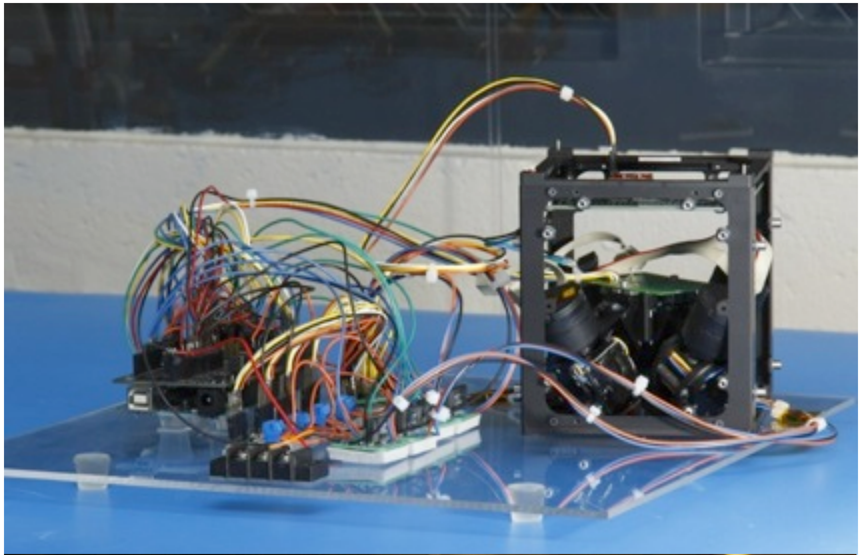
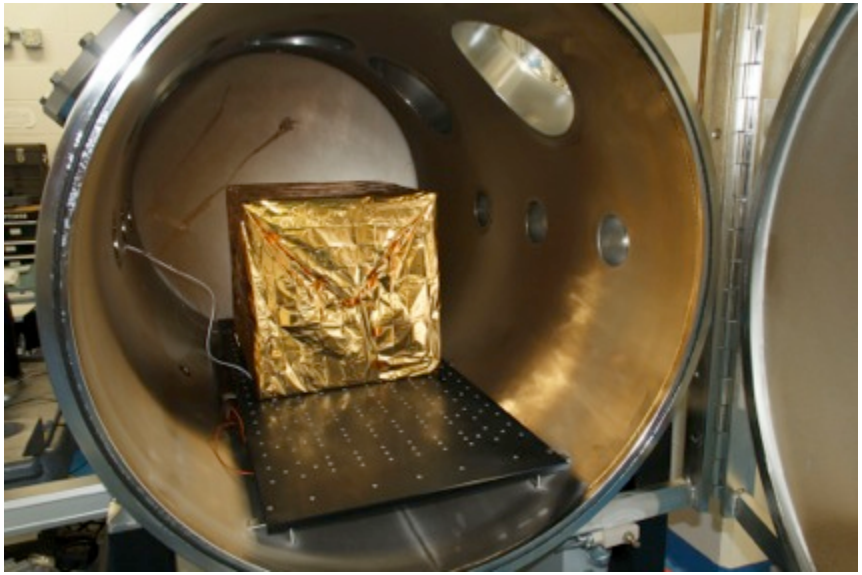
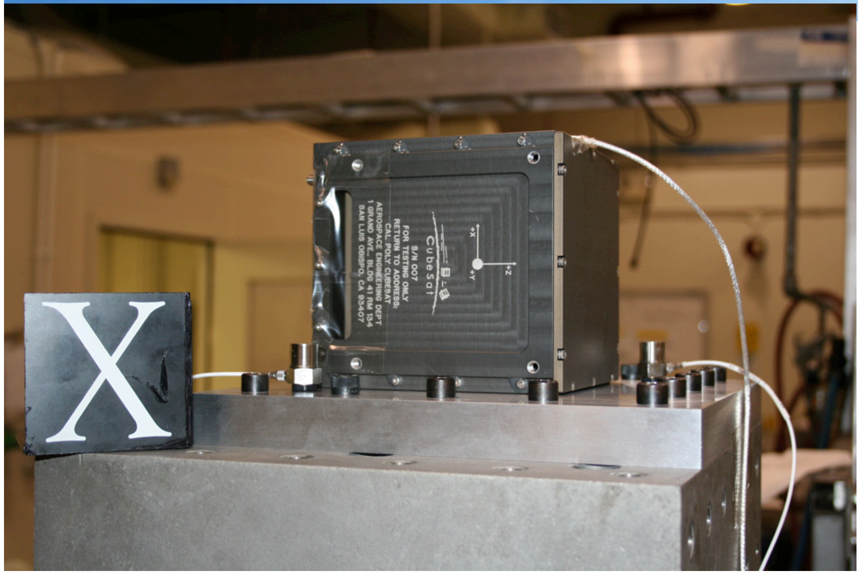
Risk Management for SwampSat

Testing in Different Environments







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Conclusion

- Utilizing a systematic systems engineering approach, a more robust system capable of adapting to potential failures was developed and implemented for SwampSat
  - Performing reliability analysis on the system identified high risk components and potential failures
  - With proper risk management and mitigation plans, those high risk components and potential failures were mitigated (and/or remediated)
- Similar systematic systems engineering approach should be adopted and implemented for other small satellite programs (especially university-based)

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