Reliability Analysis and Risk Management of SwampSat

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Overview

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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

Reliability Analysis

- 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

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

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 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).
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## Reliability Analysis: SwampSat FMECA

- **FMECA was constructed in a tabular form**

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

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November 20th, 2013, Takeda Hall, University of Tokyo, Tokyo, Japan
Reliability Analysis: SwampSat FTA

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

**Basic Failure Events:**
- 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

**CMG Controller Components:**
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

![FTA Diagram]

```
Sun Sensor Failure
<p>| |</p>
<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Burns Out</td>
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<tr>
<td>N</td>
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</table>

Magnetometer Failure
<p>| |</p>
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<tr>
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<tbody>
<tr>
<td>Saturation</td>
</tr>
<tr>
<td>M</td>
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</table>

IMU Failure
<p>| |</p>
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<tbody>
<tr>
<td>Burns Out</td>
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A/D Converter Failure
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<tr>
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<tbody>
<tr>
<td>B</td>
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CMG Controller Failure
<p>| |</p>
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<tbody>
<tr>
<td>Component (1-6)</td>
</tr>
</tbody>
</table>
```
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

Mitigation Plans and Strategies

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

<table>
<thead>
<tr>
<th>High Risk Items</th>
<th>Key Characteristics</th>
</tr>
</thead>
</table>
| 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 |
Risk Management for SwampSat

Testing in Different Environments
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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