Guatemala’s Remote Sensing CubeSat - Tools and Approaches to Increase the Probability of Mission Success

Marvin Martínez, Diego González, Diego Rodríguez, Johan Birnie, José Antonio Bagur, Ricardo Paz, Emilio Miranda, Fernanda Solórzano, Carlos Esquit, Julio Gallegos, Eduardo Álvarez, Víctor Ayerdi, Luis Zea

Presenter: Andrew Dahir, PhD Candidate.
Quetzal 1 –
The Guatemalan CubeSat

Mission:
Acquisition of multispectral images of Earth at specific wavelengths (450, 550, 680, and 700 nm) as part of the testing of an in-house-developed payload. Enabling the characterization of chlorophyll-a (Chl-a) concentrations on bodies of water as a proxy to monitor algal contamination.

Main components
- Monochromatic sensor (Crystalspace, Cat. No. CAM1U, Estonia)
- Piezoelectric motor and driver (Tekceleo, Cat. No. WLG-30, France)
- Filters (Edmund Optics, Cat. Nos. 86-653, 86-655, 88-571, 86-658, USA)
- Carousel (built-in-house)
Payload

Structure and thermal protection

Power
- 11 Azur Space’s solar cells, 2 Lithium polymer batteries, 1 current and voltage monitor.

On-Board Computer and Command & Data Handling
- GOMSpace NanoMind A3200

On-Board Communications
- GOMSpace NanoCom AX100 and ANT430 antenna.

Antenna Deployment Mechanism

Ground Control System
- Yagi Antenna, Az/EI rotor, SP-70 UHF preamplifier, HackRF SDR dongle.

Attitude Determination & Control
- K&J Magnetics 0.25”, 2 HyMu80 hysteresis rods, 12 Vishay photodiodes, 2 Texas Ins. ADC, BNO055 IMU.
TECHNICAL AND PROGRAMMATIC TOOLS TO INCREASE PROBABILITY OF SUCCESS
Requirement compliance matrix

Developed and maintained to keep an efficient control of all the requirements that the satellite has to meet.

Divided in three subcategories:

i. Mission requirements (defined by Quetzal 1 team to meet the project’s objectives)
ii. Design requirements (defined by JAXA and physical characteristics of CubeSats)
iii. Operational requirements

Each requirement is given a Unicode to keep monthly revisions.
Requirement verification and validation

The V&V matrix enables to systematically control each requirement is verified and/or validated.

The requirements must be verified with at least one of the following methods:

- Analysis
- Inspection
- Review of design
- Test

The process completes with a controlled document that specifies how the verification was performed.
Risk Matrix

The risk matrix helps identify and categorize more than 70 mission’s risks. They get a value from 1-5 (low-high) depending on:

- Likelihood
- Consequence

It develops a level of criticality of the risk (low, medium, or high).

The matrix is dynamic and changes as the project matures.
Failure mode and effects analyses (FMEA)

The FMEA matrix allows a better characterization of each risk, identifies how it will be mitigated and quantifies to what level the risk were taken care of.

Each failure mode needs before and after action results values of:

- Severity
- Occurrence
- Mitigation

<table>
<thead>
<tr>
<th>Module</th>
<th>Risk Code</th>
<th>Failure Mode</th>
<th>Potential Cause(s) of Failure</th>
<th>Severity</th>
<th>Potential Effects of Failure</th>
<th>Occurrence</th>
<th>Current Controls</th>
<th>Mitigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>C&amp;DH</td>
<td>CDH-04</td>
<td>Error in communications protocol</td>
<td>False activation, clock asynchronized</td>
<td>64</td>
<td>Interruption in communications between OBC and GCS</td>
<td>8</td>
<td>Functionality test of AX100</td>
<td>8</td>
</tr>
</tbody>
</table>

Action Results:

<table>
<thead>
<tr>
<th>Risk Priority Number (RPN)</th>
<th>Severity Category</th>
<th>Recommended Action</th>
<th>Action Taken</th>
<th>Severity</th>
<th>Occurrence</th>
<th>Mitigation</th>
<th>RPN</th>
</tr>
</thead>
<tbody>
<tr>
<td>4096</td>
<td>Critical</td>
<td>Generate AX100 functionality test report verifying clock synchronization</td>
<td>No</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
N-squared diagram

The N-squared diagram has the form of a matrix and is used to represent the functionality or physical connection between system elements.

Mostly used to define and analyze the interfaces the satellite need. It has four types of interfaces:

I. Service supplier (SS)
II. Mechanical (M)
III. Electrical (E)
IV. Software (S)
Documents control

Every document is given an unique code.
Are stored in a cloud service for everyone in the team to have access.
Must be revised by an engineer that didn’t participate in its elaboration and approved by a project director to become a controlled document.
If changes are made after becoming controlled, the old version becomes obsolete but stays in the drive.
226 documents have been created up to date.

Parts control

Every part has a unique code
A list was created and maintained recording aspects such as mass, voltage required, material composition & properties, and source vendor information.
150 different components have been recorded up to date.
Material Off-Gassing

Materials off-gassing in Quetzal 1 must be under 1% for Total Mass Lost (TML) and 0.1% for Collected Volatile Condensable Material (CVCM).

The materials properties were obtain through NASA's Material and Processes Technical Information System (MAPTIS).

Capacitor control

The aluminum electrolytic capacitors were eliminated and restricted in Quetzal 1 due to its susceptibility to physical and thermal overstress.

The mitigation of this risk was through the incorporation of tantalum capacitors, which are ideal for aerospace electronic applications.
Structural Finite Element Analysis

The Finite Element Analysis (FEA) was performed to determine if Quetzal 1 could withstand the rough launch environment. Taking into account the vibrations and accelerations described by JAXA.

The static, quasi-static, modal and random vibrations analysis were performed.

Thermal Finite Element Analysis

FEA was also used to determine the temperatures profiles experienced by the satellite in orbit. Enabling to determine the temperature range that components will need to withstand.

The heat fluxes analysis was done considering:

- Solar radiation
- Albedo radiation
- Infrared radiation
- Reflected radiation
- Heat dissipation
- Position with respect to Earth and Sun
Engineering drawings architecture and control

The architecture was designed and implemented to identify a drawing’s position in a hierarchical structure. This structure is established as the following:

1. Complete CubeSat (CST-ASY)
2. CubeSat module (ASY)
3. Module subassembly (SAS)
4. Subassembly part (PT)
Assembly procedure

The assembly procedure is a detailed document that describes, step by step, the process that must be performed to assemble the CubeSat correctly.

Is based with the intention to proactively mitigate errors or unexpected events while assembling Quetzal 1.

Each section has steps with aided images, detailed description, comment section, list of materials and tools.

The adequate torque value for each threaded part was calculated and placed to prevent loose, overtightened or damage parts.
Discussion

• The small size of a CubeSat can be deceiving, as it is a highly complex system that requires not only meticulous controls but hundreds of controlled documents, engineering drawings, requirements and risk to be monitoring to increase the odds of the mission success.

• The tools used to mitigate risk have been key to identify design errors that set the mission in a path of failure.

• This has been an effort of over a 100 undergraduate students, volunteers, and faculty at different times of the project during a four-year long design phase to get as close as possible to a 100% successful flight of the first Guatemalan Satellite.