Fly Your Satellite!

Analysis Report (ARPT)

Attitude and Orbit Control System (AOCS)

Contents

Acronyms

BOL Begin of Life

CAD Computer Aided Design

EOL End of Life

ETSETB Barcelona School of Telecommunications Engineering

EU European Union

FEM Finite Element Model

GMM Geometrical Mathematical Model

ICD Interface Control Document

IR Infrared

NOTR Non-Operational Temperature Ranges

OTR Operational Temperature Ranges

PCB Printed Circuit Board

TBD To be determined/defined

TCS Thermal Control System

TMM Thermal Mathematical Model

TRP Temperature Reference Point

VCD Verification Control Document

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APPROVAL

Title	**FYS DRD and Guidelines**		
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CHANGE LOG

Reason for change	Issue Nr	Revision Number	Date
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DISTRIBUTION

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Applicable Documents

Reference	Document Title	Issue/Release Date
RD01	ECSS-E-ST-31C Space Engineering	Issue 2, 2008/11/15
RD02	ECSS-E-HB-31-01 - Space Engineering - Thermal design handbook - Part 1 to 16	multiple
RD03	P. D.G. Gilmore, “Spacecraft Thermal Control Handbook: Fundamental Technologies”, ESA-TEC-MTT	2002

1 Introduction

The ^{Po}Cat-Lektron Thermal Analysis is aimed to verify that all the components of the spacecraft work in its operational temperature range during all mission phases. In order to develop an accurate enough model, the following approach has been considered:

First, an isothermal solid cube will serve as an initial model. After that, models considering radiation as the principal mode of heat transfer will provide more accurate results. Later on, models considering both conduction and radiation as the main modes of heat transfer will allow the needed characterization of the spacecraft to verify the thermal requirements of each component.

In this document, the isothermal analysis and the radiation analysis of the ^{Po}Cat 2 and ^{Po}Cat3 satellites are presented.

The main objective of the isothermal analyses is to identify a passive thermal control which maintains the spacecraft temperature in the correct behavior. In this case , the evaluated technique is the use of different paints on the spacecraft surface.

As for the radiation analyses, they are aimed to validate the spacecraft thermal model and verify its behavior under different heating environments.

1.1 The ^{Po}Cat-Lektron mission

1.1.1 Mission statement

The ^{Po}Cat-Lektron is a mission resulting from the IEEE OpenPocketQube Kit initiative, developed at the UPC NanoSat Lab. The mission has been selected in the 4th call of the ESA Fly Your Satellite! (FYS) program. The mission analysis presented corresponds to the ^{Po}Cat-Lektron mission. It consist of two 1P PocketQubes, the PoCat-2 and the PoCat-3, developed as a part of the IEEE OpenPocketQube Kit. This mission aims to demonstrate the feasibility of PocketQube platforms for remote sensing applications.[**?**]

The payloads on board of the PocketQubes are two passive radiometers to be use for RFI purposes on K and L bands. Apart from the remote sensing nature of the mission, this mission also aims to demonstrate the feasibility of the PocketQube platforms to create, manage and join Federated Satellite Systems. To do so, the FSS Experiment will be reproduced as a part of the experiments of the mission.

1.1.2 Mission Objectives

- **Demonstration of Scientific Viability:** Demonstrate the feasibility of conducting scientific missions using PocketQube platforms. To do so, the mission proposes collecting valuable RFI data through a K-Band and L-Band passive radiometers (One for each PocketQube). The payloads will monitor interferences on these bands. This data will facilitate enhanced detection and the generation of heatmaps indicating RFI distribution across the globe. In this experiment we aim to obtain data on the K-Band to see the impact on the atmospheric water vapor measurements, and in the L-Band the interferences over the Position Navigation and Timing (PNT) signals.
- **Satellite Federation Concept:** To establish and demonstrate that PocketQube platforms can create, manage and join Federated Satellite System (FSS). This proof of concept for this resource-limited platforms is based on the reproduction of the FSS Experiment conducted at the UPC NanoSat Lab. The demonstration consist on create a federation between 2 PocketQubes, in order to download data. Previous missions such as the FSS-Cat from the UPC NanoSat Lab demonstrated the feasibility of this opportunistic collaboration using 6U CubSats.
- **Educational Development:** As a mission developed at the UPC NanoSat Lab, the mission is oriented for undergraduated students to gain experience and get involved in real space missions. In addition, several Bachelor and Master Thesis had been done from this project, apart from the academic papers that this project has produced.

2 Simulation model

To assist the AOCS design, verification and validation, a simulation model using mathlab code has been used. The simulation is based on the Princeton Toolbox [1], which contains a set of functions and simulations initially created for CubeSats, that has been adapted to the PocketQube.

2.1 PocketQube Model

The mission is formed by two PQs, one using an L-band Radiometer and the other using a K-band radiometer. To model the PQ, a 3 dimensional cube has been used, shown in *Figure 2.1*. This cube has the same dimensions as a PQ 5x5x5 cm^2 and the same mass as the PQs. Additionally, to apply the inertia of the PQs, the inertia matrix is taken into account in the simulation.

The satellites will be simulated in two different configurations, on the one hand in stowed configuration (without the anntennas deployed) and on the other hand in deployed configuration. In the case of the L-band PQ the stowed configuration contains both the L-band antenna and communications antenna stowed.

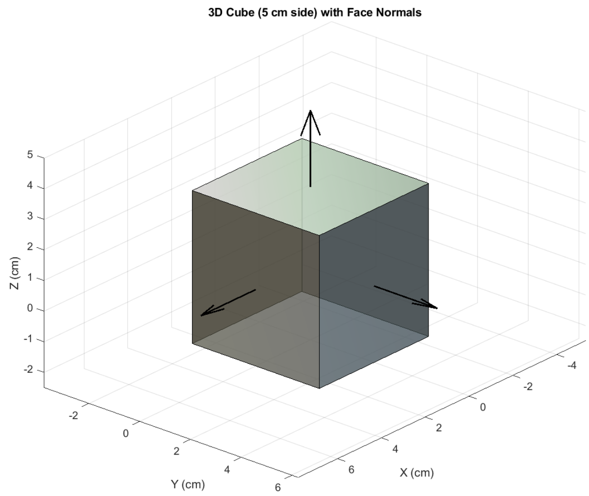

Figure 2.1: PocketQube 3D model

2.2 Environmental model and asumptions

2.2.1 Reference framse

- **Earth Centered Inertial (ECI) frame:**
  The ECI frame is a global cartesian reference frame that has its origin at the centre of the Earth.
  - X axis points to the Vernal Equinox.
  - Y axis completes the set with the right-hand rule.
  - Z axis aligned with the Earth's rotation axis.

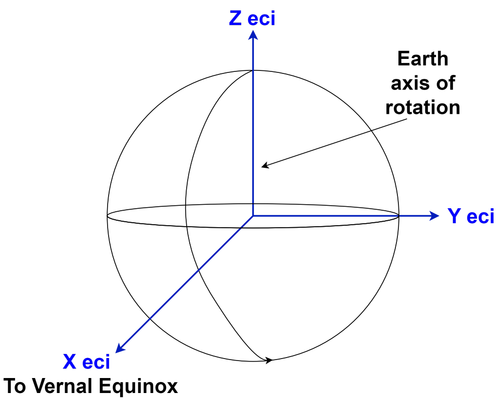

Figure 2.2: ECI frame representation

- **Body frame:**
  The Body frame is a global cartesian reference frame that has its origin at the centre of the PQ.
  - X axis aligned with the PocketQube width, parallel to the sliding plate and perpendicular to the direction of insertion into the PocketQube deployer.
  - Y axis aligned with the PocketQube length, the direction of insertion into the PocketQube deployer and completing the right handed reference frame.
  - Z axis aligned with the PocketQube height direction, pointing upwards from the sliding plate.

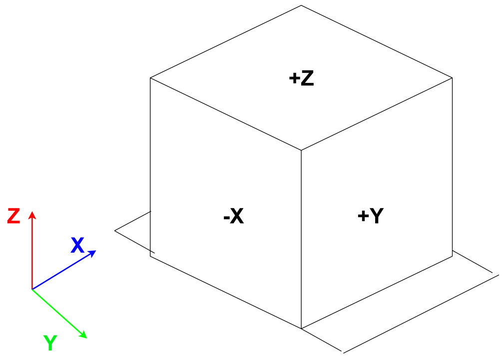

Figure 2.3: Body frame representation

- **Local Vertical Local Horizontal (LVLH) Frame:**
  The LVLH Frame will be mainly used for results presentation in the Nadir pointing simulations. The frame is described as:
  - X-Axis: Perpendicular to Y and Z, forming a right-handed coordinate system - Local Horizontal
  - Y-Axis: Negative to the orbit normal, or in the direction of -h
  - Z-Axis: Oriented in the direction of -r (points to center of Earth) - Local Vertical

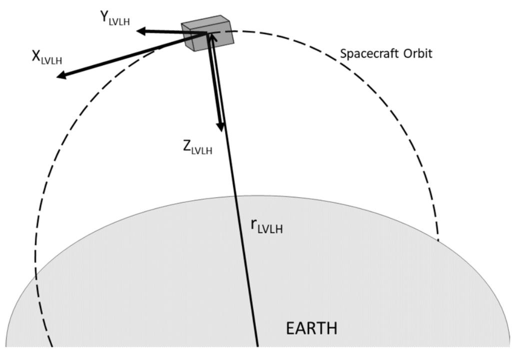

Figure 2.4: LVLH frame representation

2.2.2 Environmental models

The following environmental models are used in the simulation:

- **Earth's magnetic field model [2]:** The Earth's magnetic field model used in the simulation is based on the Tilted dipole mode, which includes the effect of the dipole motion of the Earth.
- **Aerodynamic Drag model:** The simulation uses an aerodinamic drag model based on the Jacchia's 1970 model [3].
- **Radiation Pressure model:** The simulation includes the solar radiation pressure, the earth radiation pressure and the earth albedo pressure.
- **Gravity field model:** The simulation accounts for a point-mass gravity model.

2.2.3 External disturbances

The following external disturbances are considered in the simulation:

- **Drag force:**
- **Aerodynamic torques:**
- **Gravity gradient torques:**
- **Radiation Torques:**

2.3 Orbit and attitude kinematic propagators

As for the Orbit propagator in the simulation, firstly, the used equations or motion are the Cowell' form of the two body problem, using disturbances. In addition, the integrator type used is the Runge-Kutta 4th order method. As for the propagation of the parameters, they are done in the Earth Centered Inertial (ECI) frame.
The parameters included in the initial vector for describing the state of the satellite at the begining of the simulation are:

- Satellite's position.
- Satellite's velocity.
- Satellite's attitude quaternion.
- Satellite's angular velocity.

Regarding the attitude representation of the satellite in the simulation, the mathematical expresion that will be used is the quaternion. During the simulation the quaternion that will be used is the one representing the rotation fromt he body frame to the ECI frame. However, at the time to present the results the quaternion that will be used will be the one representing a rotation from the Local Vertical Local Horizontal (LVLH) frame to the ECI frame.

2.4 Sensor and actuator models

In this section all the models used for the sensors and for the actuators are described. It is assumed that all the sensors has been calibrated and temperature characterized. A brief list of the sensors and actuators included in the PQ is presented below:

Sensors	Actuator
Gyroscope	Magnetorquer
Photodiodes	
Magnetometer	

2.4.1 Gyroscope

The model used to represent the gyroscope output given by [4] is:

$$\boldsymbol{\omega} = \boldsymbol{\omega_o} + \boldsymbol{b}(\boldsymbol{t}) + \boldsymbol{n}, \tag{1}$$

where:

- $\boldsymbol{\omega}$ is the measured angular velocity vector.
- $\boldsymbol{\omega_o}$ is the true angular velocity of the satellite.
- $\boldsymbol{b}$ is the bias term, modeled as a random walk process.
- $\boldsymbol{n}$ is a zero-mean Gaussian noise vector.

2.4.2 Photodiodes

The output of the photodiodes can be modeled as:

$$\boldsymbol{v} = \boldsymbol{v_o}(\boldsymbol{T}) + \boldsymbol{n} \tag{2}$$

where:

- $\boldsymbol{v}$ is the measured voltage output vector,
- $\boldsymbol{v_o}(\boldsymbol{T})$ is the true signal component that is dependent to the temperature $\boldsymbol{T}$ previously calibrated.
- $\boldsymbol{n}$ represents additive noise, typically modeled as zero-mean Gaussian noise.

2.4.3 Magnetometer

The magnetometer model is expressed as:

$$\boldsymbol{B}_{\text{meas}} = (\mathbf{C}_e \cdot \boldsymbol{B}_{\text{true}}) + \boldsymbol{b}_e + \boldsymbol{n} \tag{3}$$

where:

- $\boldsymbol{B}_{\text{meas}}$ is the measured magnetic field vector in the body frame.
- $\boldsymbol{B}_{\text{true}}$ is the true magnetic field vector in the body frame.
- $\mathbf{C}_e$ is the calibration matrix with errors.
- $\boldsymbol{b}_e$ is the sensor bias error vector.
- $\boldsymbol{n}$ is zero-mean Gaussian white noise with known variance.

2.4.4 Magnetorquer

The magnetorquers are simulated as a mathematical formula. The magnetorquers generate a magnetic moment depending on the injected intensity, therefore, in the simulation this magnetic moment is calculated and later used to propagate the following attitude of the satellite with the other external disturbances. The formula used for calculating the magnetic moment generated by the magnetorquers is:

$$\boldsymbol{m} = I_o N_{layers} \sum_{i=1}^{N_{turns}} (l - 2(i-1)(w+d))^2 \tag{4}$$

Where the l is the length of the magnetorquer, the w the width of the copper trail, the d the distance between trails, N_{layers} is the number layers in which the magnetorquer is divided and N_{turns} is the number of turns in the magnetorquer. The I_o is the injected current, which is the input of the magnetorquer. The table below shows the characteristics of the magnetorquers used in the simulation:

Board	**Turns**	**Max moment (A·m^2)**	**Dimensions (mm×mm)**	**Layers**
Top	42×layer	9.17×10^{-4}	32 × 32	4
Bottom & Lateral	38×layer	0.0017	32 × 32	4

2.5 Simulaton / model sampling times and frequencies

The simulation time used is 2 seconds which corresponds to 0.5 Hz. This is due to the fact that the on board computer (OBC) used in the PQ only has one thread to manage all the tasks, therefore, the sampling frequency has been chosen thinking in the worst case scenario. The sampling time of the sensors is the same one as the simulation time.

3 Simulation performance campaign plan and results

In this section the simulation results of the two different operational modes of the ADCS in the PQ are presented.

3.1 Nadir Pointing Mode

The objective of the Nadir Pointing is to point the Payload located at the top board of the PocketQube towards the Earth, so that the Payload can take measurements of the Earth. For this mode the following requirements have been defined:
The Absolute Performance Error (APE) of the Payload boresight shall be less than 20º with respect to the Y and X axes, which are the axes perpendicular to the boresight, and this requirement should be met for 95% of the time.

The PocketQube will be in deployed coniguration during the simulation.

3.1.1 Assumptions and limitations

The list below presents the different assumptions and aspects considered to perform the simulations.

- **Orbit parameters**
  - Inclination: 90 degrees
  - Altitude: 500 Km
  - Eccentricity: 0 degrees
  - Initial satellite position: [6887 , 0 , 0] Km
  - Initial satellite velocity: [0 , 0 , 7.6] Km/s

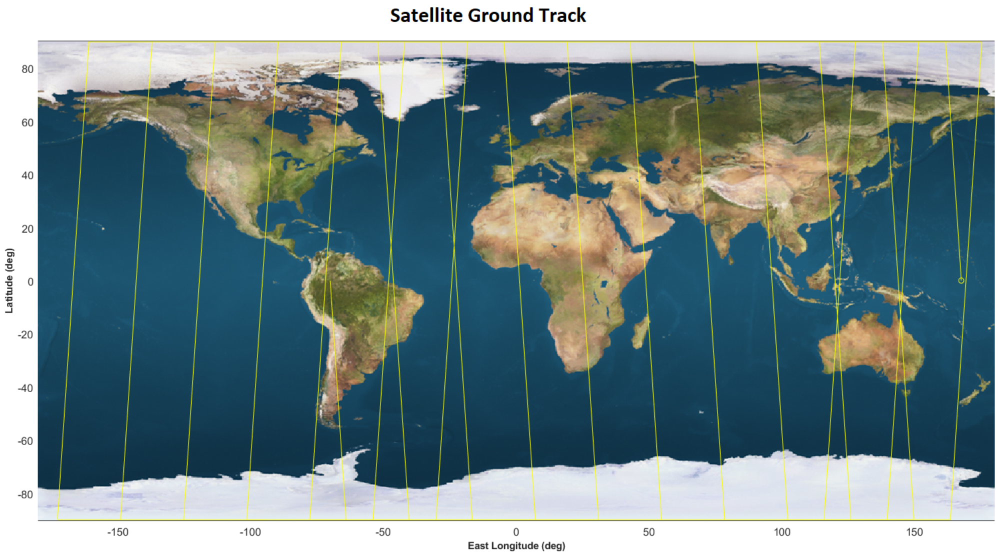

Figure 3.1: Ground track of the simulated PocketQube orbit

- **Number of simuated orbits:** 10 orbits
- **Simulation starting date:** 05/04/2027 00:00:00 UTC
- **Simulation time step:** 2 seconds

3.2 Detumbling mode

References

[1] Princeton University. Created toolboxes. https://psatellite.com/, 2017.

[2] Wikipedia. Dipole model of the Earth's magnetic field. https://en.wikipedia.org/wiki/Dipole_model_of_the_Earth%27s_magnetic_field, 2025.

[3] Johnson,D.L and Smith, R.E. The MSFC/J70 orbital atmosphere model and the data bases for the MSFC solar activity prediction technique. https://ntrs.nasa.gov/citations/19860012552, 1985.

[4] F. L. Markley and J. L. Crassidis,. Fundamentals of Spacecraft Attitude Determination and Control, 2014.