2nd IAA Latin American CubeSat Workshop- Florianopolis - SC, Brazil

IAA-BR-16-1P-01 Mission analysis for a remote sensing CubeSat mission over the Amazon rainforest

Gabriel Gustavo Coronel Mariño*1, Eduardo Escobar Bürger*2, Geilson Loureiro*3, Otávio Luiz Bogossian*4

* National Institute for Space Research (INPE), Brazil

1 gabrielg.coronelm@gmail.com; 2 eduardoebrg@gmail.com; 3 geilson@lit.inpe.br; 4 otavio.bogossian@inpe.br

Ministério da Ciência, Tecnologia e Inovação

GOVERNO FEDERAL BRASIL PÁTRIA EDUCADORA

INTRODUCTION

The Systems Concurrent Engineering Laboratory (LSIS) of the Laboratory of Integration and Testing (LIT) of the Brazilian National Institute for Space Research (INPE) has functions such as explore concepts and propose viable solutions for complex systems as satellite systems. Due to one of its recent projects, the AESP14 CubeSat, the LSIS has begun to offer nanosatellite consultancy services.[1] As an exercise to explore concepts, assess mission viability and develop a mission analysis process tailored for CubeSats for its use in the LSIS, it was proposed the study of a remote sensing CubeSat mission over the Amazon rainforest. In order to have all the inputs for mission analysis, some previous assumptions were taken following the Space Mission Analysis and Design (SMAD) process[2].

- **Subject: The Amazon rainforest** (due to its world importance as "lungs of the world" and the concerns about global warming that have been growing in recent years.[3]).
- **Objectives:** Simplified to taking images in the visible spectral range for later deforestation analysis.
- **Mission concept:** the CubeSat was thought to be launched from the International Space Station (ISS), orbiting around the Earth while taking images every time that subsatellite point is over the Amazon rainforest and the target region is illuminated by the Sun (since camera was assumed as optical). Simultaneously, every time that the CubeSat has radio visibility with the Aeronautics Institute of Technology's (ITA) ground station, located in São José dos Campos, Brazil, the CubeSat is expected to send real-time transmission or on-board stored images. Subsequent mission operations with the received data by the ground station were considered outside the scope of this paper.
- **Mission architecture:** Chosen elements are showed in Table 1.

	Mission architecture elements	
Subject	Amazon rainforest	
Payload	GOMX NanoEye CubeSat[6]	NanoCam C1U
Spacecraft bus		GOMX-Platform
Launch system	Nanoracks small satellite deployment system from ISS	
Orbit	~ISS orbit (initially)	
Ground system	ITA's ground station	
Communications architecture	Outside of the scope	
Mission operations	Outside of the scope	

Table 1. Mission architecture elements

METHODOLOGY

1. Obtainment of ISS's orbital parameters for January 1st, 2018 (UTGC 00:00:00.000)

- **Remarks:** The ISS's semi-major axis obtained by STK[7] was not completely accurate since reflected an altitude lower than the ISS's operational range (385 and 425 km[5]). This could be due to the fact that STK was possibly using input orbital parameters from its satellites database and then propagating them to the chosen date and time without any considerations of maneuvers. Then, to avoid this misleading result, the ISS's semi-major axis was modified according to **two scenarios: the first with the ISS at an altitude of 385 km at perigee** and **the second with the ISS at an altitude of 425 km at apogee**. Other classical elements' values were kept even when they could change with altitude maneuvers. Change was made just to altitude since this element has a key effect on coverage, resolution and survivability[2], so it was considered as the most important for mission analysis.

2. Simulation of the CubeSat's deployment from the ISS

- **Remarks:** Deployment was simulated in GMAT through a maneuver with a ΔV of 1.7 m/s in a direction angle of 45° from nadir to aft axis of the ISS (simulating a deployment from the Nanoracks small satellite deployment system[4]).

The CubeSat's initial classical elements after the deployment for both scenarios are showed in Table 2.

Orbital element	Semi-major axis (km)	Eccentricity	Inclination (°)	Right ascension of ascending node (°)	Argument of perigee (°)	True anomaly (°)
First Scenario	6770.746	0.001740	51.723	71.931	115.815	174.394
Second Scenario	6790.984	0.001740	51.723	71.931	115.806	174.403

Table 2. The CubeSat's initial classical elements after deployment for both scenarios.

3. Propagation of the CubeSat's orbit considering the atmospheric drag

- **Remarks:** Atmospheric drag is the principal non-gravitational force acting on most satellites in low-Earth orbit. It slows the satellite and removes energy from its orbit. This reduction of energy causes the orbit to constantly get smaller until the satellite reenters the atmosphere.[9] Parameters chosen for the propagation in GMAT are showed in Table 3 (selections were made based on other references studies[9]-[12]).

Parameter	Value
Force model gravitational field	Earth Gravitational Model 1996 (EGM96)
Propagator	PrinceDorman78
Drag coefficient	2.2
Atmosphere model	Mass Spectrometry and Incoherent Scatter (MSISE90)

Table 3. Parameters set in GMAT.

4. Export of CubeSat's ephemerides from GMAT

5. Set-up of STK scenario with GMAT ephemerides and ITA's ground station

- **Remarks:** Location parameters of ITA's ground station were obtained by Google Earth Pro and a height above the ground of 15 m was assumed. The required minimum elevation angle was set up to 15° in order to take into account the effects of obstacles such as high buildings.[13]

6. Performance of the analyses

- **Three analyses:** Lifetime, payload performance and communication link.

RESULTS AND DISCUSSION

1. LIFETIME ANALYSIS

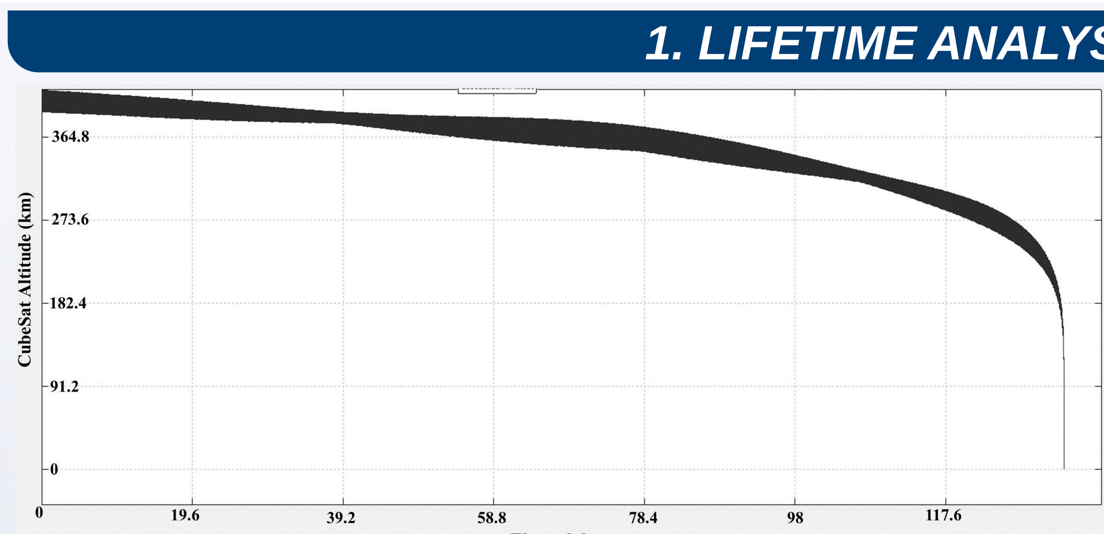

Figure 1. First scenario - CubeSat altitude (*y* axis) against elapsed days (*x* axis) when initial altitude is 385 km at perigee.

Simulations showed that the CubeSat decayed approximately after 120 days (4 months) when deployed at 385 km (Figure 1) and 180 days when deployed at 425 km (Figure 2).

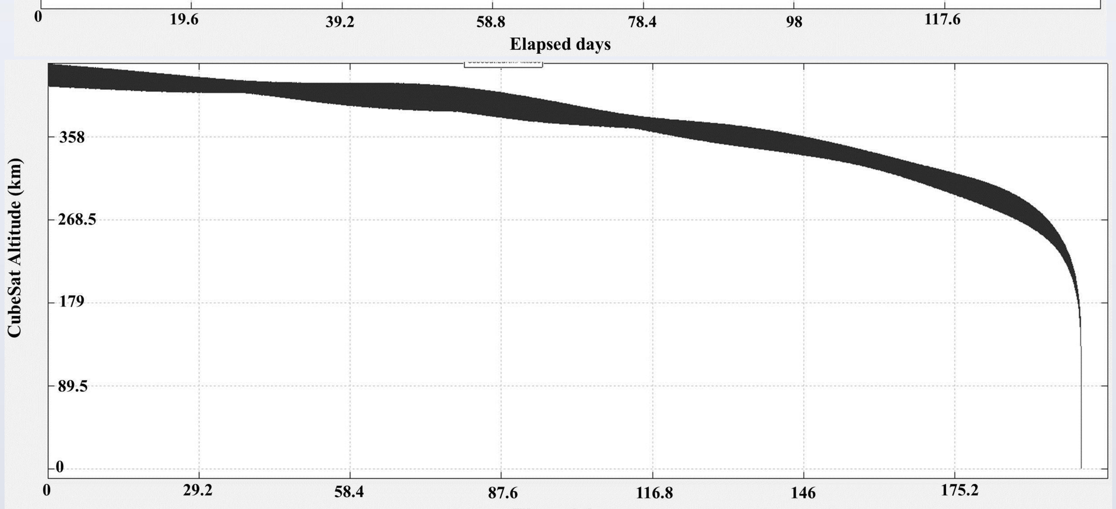

Figure 2. Second scenario - CubeSat altitude (*y* axis) against elapsed days (*x* axis) when initial altitude is 425 km at apogee.

2. PAYLOAD PERFORMANCE ANALYSIS

The NanoCam C1U payload is a Complementary Metal–Oxide–Semiconductor (CMOS) sensor. CMOS sensors have been the trend in CubeSats as they consume less power and can be used for longer time in space in comparison with CCD sensors[14]. Specifications are shown in Tables 4 and 5.

Parameter	Value
Number of pixels	3 MP (2048 x 1536)
Spectral band	RGB 400-1000 nm
Radiometric resolution	10 bit
Field of View	9°
Pixel pitch	4.308 μm
Focal length	35 mm
Max. frame rate	3 fps
RAM memory	512 MB
Solid state storage	2 GB

Table 4. NanoCam C1U payload specifications[16]-[17].

Parameter	Value
Pointing capacity	Yes
Attitude knowledge accuracy	5°
Attitude control accuracy	10°

Table 5. Payload pointing specifications[6].

The CubeSat could point outside of the area of interest during its orbit. However, it is expected to obtain some images over the area of interest due to the several passes that the CubeSat would have until decay. Further attitude analysis in order to confirm this hypothesis and know the actual pointing limitations were kept outside of the scope of this work.

Pixel pitch and later GSD for different altitudes were calculated using Equation 1[15]

$$\frac{\textit{Focal lenght } (f)}{\textit{altitude}} = \frac{\textit{Pixel pitch}}{\textit{Ground Sample Distance } (GSD)} \quad \text{[Equation 1]}$$

Amazon rainforest was almost completely scanned using the CubeSat (Figure 3).
It was covered mostly in the first two months.

Figure 3. First scenario - Accesses between the CubeSat´s payload and the Amazon rainforest (in yellow the areas that were scanned by the CubeSat).

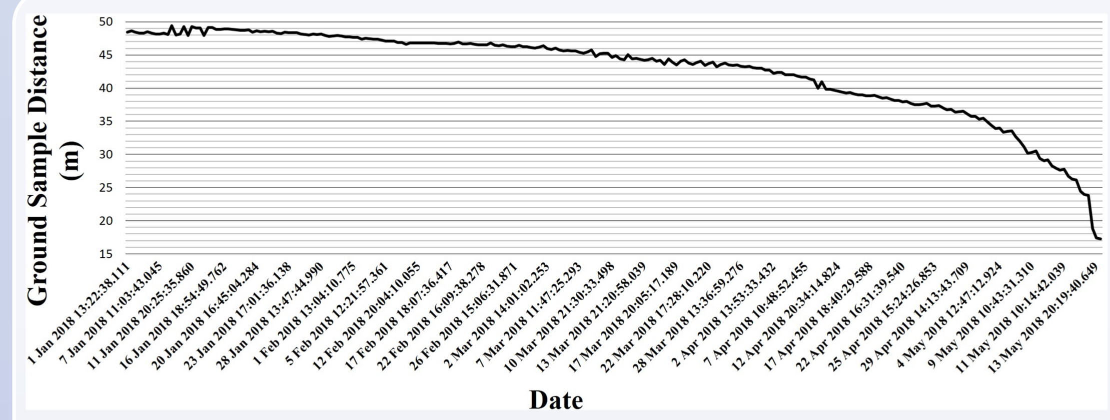

Figure 4. First scenario - GSD against date when initial altitude is 385 km at perigee.

Little difference among the Ground Sample Distance's (GSD) values in both scenarios (GSD~30-55m until the CubeSat decayed). That range of GSD would allow the discrimination between forest and non-forest areas, and also the identification of old and young woody secondary vegetation in the Amazon environment[18].

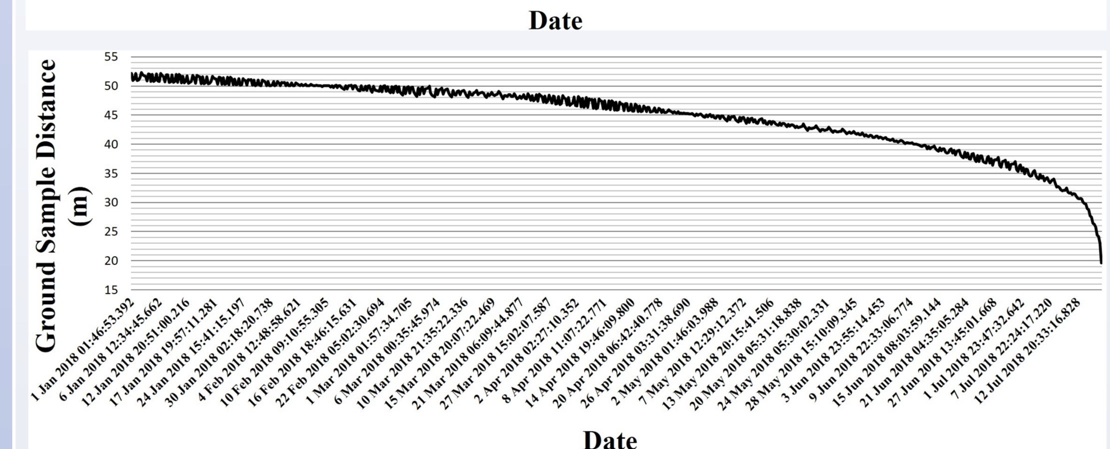

Figure 5. Second scenario - GSD against date when initial altitude is 425 km at apogee.

Payload performance in terms of accesses, gaps and the numbers of images that should be taken is summarized in Tables 6 and 7.

	Number of accesses	Longest access duration (min)	Shortest access duration (s)	Average access duration (min)	Number of gaps between accesses	Longest gap duration (h)	Shortest gap duration (s)	Average gap duration (h)
First Scenario	244	6.74	8	3.43	244	34.49	7.2	13
Second Scenario	700	6.76	3.5	3.59	700	13.13	3.6	6.78

Table 6. Payload performance summary 1: accesses, gaps and durations.

	Avg altitude (km)	Avg GSD (m)	Avg projection on the Earth´s surface (km)	Required frame rate (fps)	Number of images that should be taken during the longest access	Number of images that should be taken during the shortest access	Number of images that should be taken on avg per pass
First Scenario	359.773	44.28	68	0.107	44	1	23
Second Scenario	372.935	45.10	75	0.102	42	1	23

Table 7. Payload performance summary 2: GSD, required frame rate and images that should be taken per pass.

Summarizing payload performance:

- **It is convenient to deploy the CubeSat when the ISS is at its highest altitude** (similar GSD and average access time with a increase in the number of access and the lifetime and a reduction in the duration of gaps between accesses almost to the half).
- Up to this analysis, payload performance would satisfy mission objectives.

3. GROUND STATION COMMUNICATION ANALYSIS

Data transceiver system of the CubeSat, according to its specifications[18], could downlink data to ground stations at data rates from 1200 bps to 9600 bps.

	Number of accesses	Longest access duration (min)	Shortest access duration (s)	Average access duration (min)
First Scenario	295	5	30	3.63
Second Scenario	438	5.4	21	3.9

Table 8. CubeSat to ground station communication access summary.

	First scenario			Second scenario		
	1200 bps	4800 bps	9600 bps	1200 bps	4800 bps	9600 bps
Images that could be sent during the longest access	0.012	0.047	0.094	0.012	0.050	0.099
Passes required to deliver one image	112 (~45 days)	27 (~9 days)	13 (~4 days)	101 (~43 days)	24 (~10 days)	12 (~4 days)

Table 9. Summary of communication link performance for delivering the images taken by the payload.

Limitations of fulfilling mission objectives appeared due to the transceiver limitations.
While payload performance showed that the CubeSat is able to take several images during each pass, it would need several passes to download one image. Then, there would be only images of some specific and small areas and consequently, mission objectives would not be accomplished.
Possible solutions:

- Increase the data rates of the data transceiver system of the CubeSat using S-band transceivers (maximum data rate of 256 kbps[20]). This would allow the CubeSat to send 2.5 images and 2.6 images during the longest accesses of first and second scenario, respectively. Even this number of images is not large enough compared to the number of images that could be taken during each pass over the Amazon rainforest. To provide higher transmission rates at S-band (up to 10 Mbps) or X-band (up to 500 Mbps), the satellite must be scaled up into a larger satellite[21].
- Change mission objectives in order to reduce the area of interest or to choose some specific and small areas of the Amazon rainforest as areas of interest.
- Use a CubeSats constellation or other satellites for the downlink of images.

Link budget analysis was also performed using the AMSAT-IARU link model[22]. **For both scenarios**, **links closed with enough margin** using specifications of CubeSat antenna[23] and transceiver[19] equipment. Summary of these specifications can be seen in Table 10.

Parameter	Value
Modulation	Minimum-shift keying (MSK)
Transmitted power	2 W (33 dBm)
Antenna type	Canted Turnstyle
Antenna gain	2.0 dBi
Data rate	9600 bps
Link frequency	437.425 MHz

Table 10. Antenna and transceiver equipment specifications.

CONCLUSIONS

- A CubeSat mission for remote sensing applications, such as deforestation analysis, has limitations on its data transmission rates for delivering a big number of images to a ground station.
- Even when optical performance of the payload could fulfill the mission objectives of taking several images over the Amazon rainforest, data transmission rates of common commercial CubeSats, limit the number of images than can be transmitted to ground stations. Then, mission objectives requiring continuous coverage would not be fulfilled.
- One solution to these limitations is to use transmission frequencies on the S-band or higher in order to use transmit at higher data rates. However, this would require using state-of-the-art transmission equipment and would increase the size of the CubeSat.
- Another solution would be to adjust mission objectives in order to reduce the areas of interest or to choose some specific and small areas of the Amazon rainforest as areas of interest. Furthermore, other solutions could be the use of a CubeSats constellation or the use of other satellites for the downlink of images.
- Other results obtained by this work showed that if the altitude of deployment of a CubeSat from the ISS could be chosen, then, it is better to choose the highest altitude. By doing this, lifetime could be increased up to 2 months and the number of accesses and average duration of each could be increased too, affecting very less the payload performance.
- Further studies should be performed regarding the pointing limitations since some of the areas that the CubeSat should cover according to simulations could not be covered in a real scenario due to its attitude control accuracy.

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ACKNOWLEDGMENTS: The authors would like to thanks the CAPES, the INPE and the LIT for financial support and tools used to develop this work.