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Preliminary Mission Analysis of the Perceive Satellite: Data Acquisition and Communication for the Cerrado Biome

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Abstract: The Perception System is an integrated solution for the collection, transmission, storage, and processing of environmental data, designed to support the monitoring of strategic ecosystems. Its pilot project focuses on scalable Remote Monitoring Units (RMUs), composed of two key components: the Central Micrometeorological Tower (CMT), which measures atmospheric and surface parameters such as radiation, energy fluxes, and carbon exchange; and the Soil Monitoring Cell (SMC), which captures soil moisture, quality, temperature, and humidity. Together, these elements generate data to assess the health of different biomes. When deployed as a network, RMUs can support AI-driven predictive models to assess the impact of climate change and land use on the Cerrado Biome, an ecosystem vital to Brazil's water security, agriculture, and public health. The Perception System includes two satellite communication links: a High-Data-Rate Link (HDL) for bulk data transmission, and a Low-Data-Rate Link (LDL) used for the Perception Addressing and Reporting System (PARS), enabling low-bandwidth communication for system health and mission-critical telemetry. This paper presents the preliminary mission analysis of the Perceive satellite, with a focus on monitoring operations in the Cerrado. The analysis includes orbital dynamics, revisit time, and re-entry timelines. Different orbital configurations are compared in terms of inclination, altitude, and eclipse duration. Communication performance between the satellite, ground station, and RMUs is evaluated through contact analysis and visualized using contact opportunity graphs. Additionally, a navigation analysis estimates the daily contact frequency and assesses whether the satellite's data handling capacity meets the expected output from various RMUs deployed across the Cerrado.

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1 Introduction

Environmental monitoring of strategic ecosystems has become increasingly critical in the context of climate change and sustainable development. The Cerrado biome, recognized for its role in supplying freshwater to major Brazilian watersheds, faces mounting pressures from land-use change, deforestation, and water scarcity. Reliable, high-resolution data on atmospheric and soil parameters are essential to assess ecosystem health, inform policy decisions, and support mitigation strategies.

The Perception System is conceived as an integrated satellite-based solution for remote data acquisition, transmission, and processing. It aims to deliver cost-effective, scalable satellite services for environmental applications. Its initial pilot deployments include connection to the LBA program's

K34 tower in the Amazon for carbon-flux monitoring and reactivation of an environmental tower at the University of Brasília's Água Limpa Farm in the Cerrado [1].

The use of nanosatellites in Brazil has expanded since 2014, beginning with NanosatC-BR1 and continuing through to AlfaCrux [2], highlighting the potential of CubeSat missions for operational Earth observation and data relay, particularly for transmitting critical data over low-data-rate links, as is the case with the Perceive satellite. These developments underscore the potential for small satellite constellations to provide timely, geographically distributed measurements at a fraction of the cost of traditional platforms [1].

This paper focuses on the Perceive satellite, which is responsible for strategic data communication within the Perception System, and presents a preliminary mission analysis.

2 Methodology

2.1 System Architecture Overview

The Perception System is an integrated architecture designed for scalable, real-time environmental monitoring. It leverages two satellite-based communication networks to collect data from ground-based sensor suites, creating a relay network that enables continuous monitoring of strategic ecosystems. At the core of the system are Remote Monitoring Units (RMUs), which consist of two primary components: the Central Micrometeorological Tower (CMT), responsible for measuring atmospheric and surface variables such as solar radiation, turbulent energy fluxes, and net carbon exchange; and the Soil Monitoring Cell (SMC), which monitors soil conditions, including moisture, temperature, humidity, and quality indicators.

These RMUs feed data into a multi-layered Information Technology (IT) architecture that includes edge aggregation devices, real-time dashboards, and a tiered data management system for storage, access, analysis, and visualization. To mirror the operational environment and support advanced analytics, the system employs a five-dimensional Digital Twin (DT) model. This model is composed of physical elements, virtual elements, data descriptions, system services, and the interconnections among these components. The DT framework enables predictive modeling, anomaly detection, and scenario testing by synchronizing live sensor data with simulated system behavior.

The architecture is structured according to Model-Based Systems Engineering (MBSE) principles, implemented using the Arcadia/Capella methodology. This approach defines the system across four layers, operational, system, logical, and physical, ensuring traceability from high-level mission scenarios down to software and hardware implementations.

Communication between RMUs and the satellite network is handled via a dual-link strategy. A High-Data-Rate Link (HDL) transmits bulk datasets from ground sensors to the satellite, while a Low-Data-Rate Link (LDL), implemented by the Perceive satellite, supports telemetry, health monitoring, and the exchange of mission-critical data under constrained bandwidth conditions.

2.2 Simulation-Based Evaluation of Orbital Parameters

In this study, we employ digital engineering simulation tools to characterize the orbital parameters of the Perception mission, with a primary focus on the Systems ToolKit (STK) software [3]. The objective is to evaluate how variations in orbital elements—such as eccentricity, inclination, altitude, and eclipse duration—along with different Local Times of the Ascending Node (LTAN), influence the satellite's ability to support environmental monitoring over targeted regions of the Cerrado biome.

STK is a widely adopted platform in the aerospace sector for orbit modeling and mission analysis, known for its computational accuracy, flexibility, and capability to simulate complex space mission scenarios. A recent application of this tool is demonstrated in [4]. In this context, STK is used to model multiple orbital configurations and simulate satellite-ground contact dynamics, which are critical for assessing data availability and communication link performance between the Perceive satellite and ground-based Remote Monitoring Units (RMUs).

By systematically varying orbital parameters and analyzing their impact on coverage, visibility windows, and contact frequency, we aim to identify an optimal mission configuration that ensures reliable data throughput while meeting the system's operational constraints.

3 Results and Discussion

3.1 Orbit configuration

CubeSat-type satellites are compact and modular platforms whose missions are largely constrained by the characteristics of their deployment orbit, particularly altitude and inclination [5]. These satellites are frequently launched as secondary payloads in rideshare missions, where a single launch vehicle delivers multiple satellites into a shared orbit. This approach represents one of the most viable deployment strategies for the Perceive satellite network. Table 1 summarizes representative launch missions from three different commercial providers.

Table 1.: Rideshare launch history for the years 2023 and 2024 [6].

Mission	Company	Altitude (km)	Inclination (°)	Date
Beginning of the swarm	Rocket Lab	520	97.0	apr/24
Prefire & Ice	Rocket Lab	525	97.5	jun/24
Transporter-12	SpaceX	500	97.4	jan/25
Transporter-11	SpaceX	510	97.44	aug/24
Victus Nox	Firefly Aerospace	550	97.7	sep/23

Although rideshare opportunities offer significant cost savings on launches, they often do not guarantee that the insertion orbit will precisely match the specific requirements of each mission. This limitation is critical because orbital parameters, particularly altitude and inclination, directly influence several key aspects of the system, including geographic coverage and revisit frequency, sensor sensitivity and performance, exposure to the space environment, orbital lifetime, conditions for ground communication, and even compliance with legal and international policies. Consequently, analyzing mission behavior under various orbital configurations is essential to ensure the robustness of the system architecture. Such analysis increases margins of success and enhances adaptability when facing operational uncertainties.

Considering the geographical distribution of the RMUs and the LODESTAR UnB and University of Vigo ground stations (GS), as detailed in Table 2, and their direct impact on satellite access time to ground infrastructure — as well as the launch constraints outlined in Table 1 — an analysis will be conducted focusing on two primary orbital configurations: a Sun-Synchronous Orbit (SSO) and a Medium-Inclination Orbit (MIO). The objective is to evaluate which configuration offers better communication performance with the ground segment. For both cases, an average orbital altitude of 550 km is assumed, providing a suitable balance between surface coverage and orbital lifetime. Figure 1 shows the analyzed ground stations along with the ground track of the SSO and MIO orbital configurations.

Table 2.: Geographical coordinates and altitude of RMU and GS.

Station	Latitude (deg)	Longitude (deg)	Altitude (km)
Chapada dos Veadeiros RMU	-14.1165	-47.7119	1.19573
Fazenda Água Limpa RMU	-15.9538	-47.9175	1.12095
LODESTAR - UnB GS	-15.7616	-47.8740	1.03023
University of Vigo GS	42.2388	-8.71658	0.06880

To define the second orbital configuration for comparison, it was necessary to determine the optimal inclination for Medium-Inclination Orbit (MIO) that maximizes communication with the net-

Figure 1.: Representation of the analyzed ground stations and the ground tracks of the SSO and MIO orbital configurations.

work of ground stations. Parametric studies were conducted using STK [4], simulating a range of orbital inclinations to identify the one that provides the highest cumulative access time across all stations.

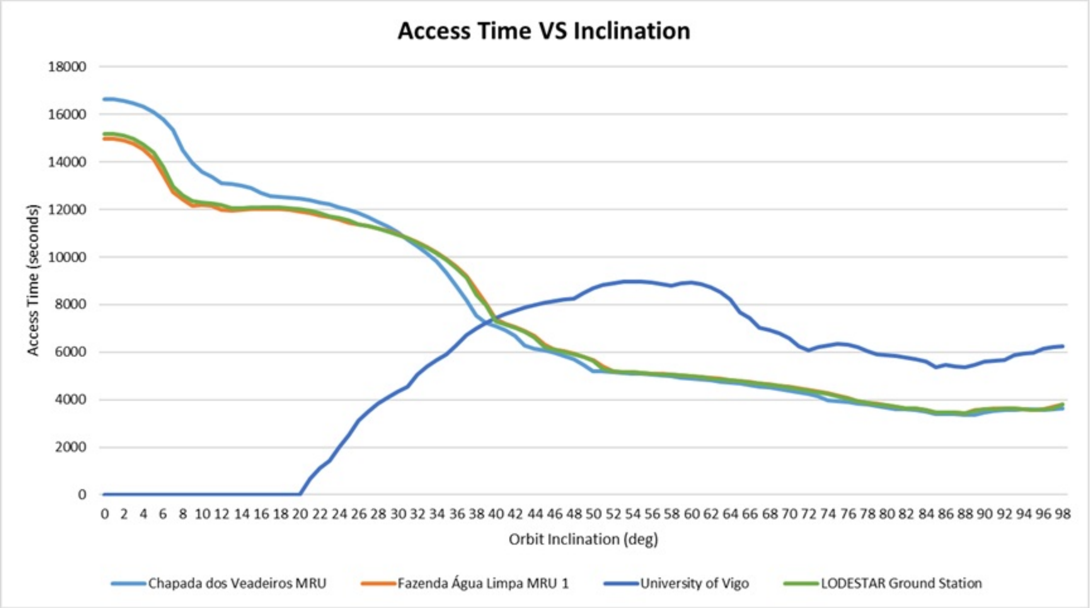


Figure 2.: Inclination angle assessment in relation to communication time with ground stations

Figure 2 presents the results of the inclination versus communication time analysis, indicating that an inclination of 40° is optimal for the evaluated scenario. This inclination offers the best trade-off between access to ground stations and revisit frequency over the Cerrado region, thereby maximizing overall mission performance in terms of data collection and transmission. A comparative summary of the two mission architecture configurations — Sun-Synchronous Orbit (SSO) and Medium-Inclination Orbit (MIO). Based on these orbital configurations, a discretized and comparative analysis of their orbital behavior can now be performed.

Simulations were conducted to assess the revisit times for both the MIO and SSO configurations over the locations of the RMUs and ground stations. A comparative analysis of the results is detailed in Table 3.

Table 3.: Comparative analysis of daily revisits for MIO and SSO orbits.

Station	**Metric**	**Orbit Type**	
		MIO (40°)	**SSO (97.4°)**
Chapada dos Veadeiros RMU	Daily Passes (avg. duration)	7 (10.0 min)	4 (10.4 min)
	Total Daily Access (hours)	2.2	1.4
Fazenda Água Limpa RMU	Daily Passes (avg. duration)	7 (9.8 min)	4 (10.4 min)
	Total Daily Access (hours)	2.3	1.4
LODESTAR - UnB GS	Daily Passes (avg. duration)	7 (9.8 min)	4 (10.4 min)
	Total Daily Access (hours)	2.3	1.4
University of Vigo GS	Daily Passes (avg. duration)	6 (11.3 min)	6 (8.8 min)
	Total Daily Access (hours)	2.0	1.7

The results indicate that the MIO configuration provides a higher number of daily passes over the Brazilian ground assets, suggesting greater robustness for data collection. However, the SSO architecture was ultimately selected for the mission baseline. This decision is primarily justified by the greater availability of cost-effective rideshare launch opportunities, which predominantly target sun-synchronous orbits. Furthermore, SSO is a well-established and mature orbit for Earth observation and communication missions, aligning with the project's strategy of leveraging proven technologies to minimize risk.

An analysis of the mission's orbital lifetime was also performed to ensure compliance with international space debris mitigation regulations. Guidelines such as those issued by the Federal Communications Commission (FCC) mandate that satellites launched into Low Earth Orbit (LEO) after September 29, 2024, must deorbit within 5 years of mission completion [7]. Using STK's Lifetime Tool, the orbital decay for the SSO configuration was simulated from an altitude of 550 km. The simulation utilized the Jacchia-Roberts atmospheric model with a projected launch date in late 2026 to account for the corresponding solar flux conditions [8].

The results, shown in Figure 3, predict that the satellite will naturally decay to an altitude of 250 km in approximately 3.5 years, well within the regulatory 5-year limit. This altitude is often considered a practical threshold, as the orbital decay rate below this point increases dramatically, and the high angular velocity relative to the ground makes tracking by ground stations prohibitively difficult.

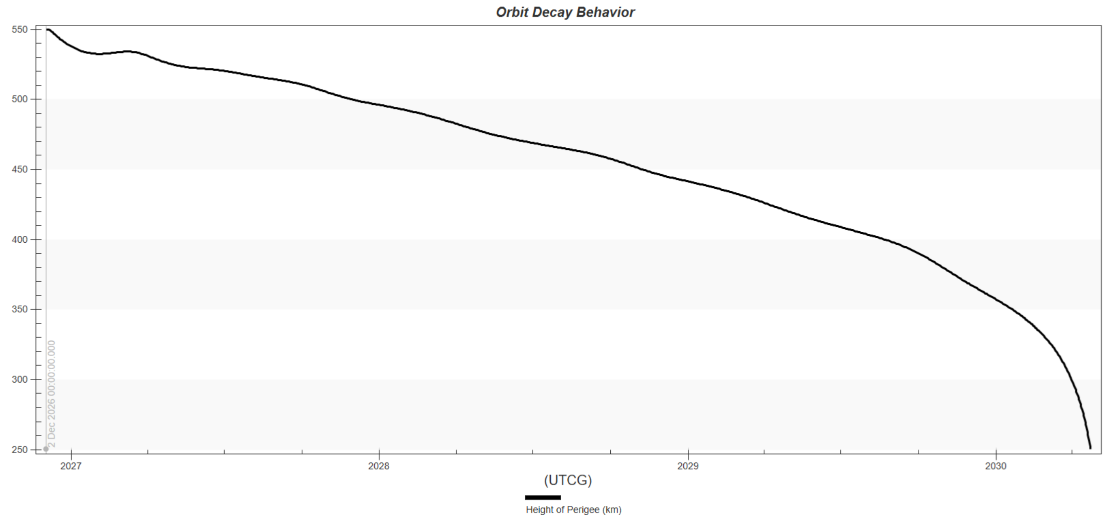
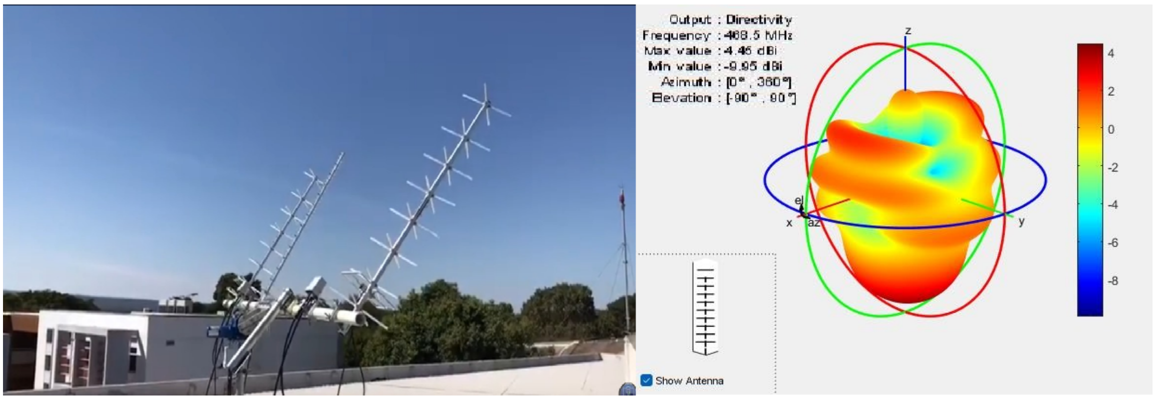


Figure 3.: Orbital decay of the Perceive satellite in the SSO configuration (550 km).

3.2 Communication Analysis

The viability of the Perceive mission is critically dependent on a robust and reliable communication link between the satellite and the ground segment. To validate the proposed architecture, a preliminary link budget analysis was performed. The communication system is designed to operate in the Ultra High Frequency (UHF) band, utilizing a frequency of 401.5 MHz for the uplink and 468.5 MHz for the downlink.

For sizing and worst-case analysis purposes, the study focused on the downlink, as it represents the most critical scenario due to the satellite's limited transmission power. The link modeling and simulation were conducted using the Systems Tool Kit (STK) software. For this simulation, a digital model of the LODESTAR ground station antenna was developed, and the resulting radiation pattern is shown in Figure 4. Additionally, the parameters of the satellite's communication subsystem were based on components and technologies with flight heritage from the AlfaCrux mission, lending greater fidelity to the results of this preliminary analysis. Table 4 summarizes the key link performance parameters, calculated using average values obtained during the satellite's passes over the LODESTAR ground station.



Output : Directivity
Frequency : 468.5 MHz
Max value : 4.45 dBi
Min value : -9.95 dBi
Azimuth : [0° , 360°]
Elevation : [-90° , 90°]

☑ Show Antenna

Figure 4.: Left: LODESTAR Ground Station antennas. Right: Modeled radiation pattern.

Table 4.: Downlink budget results for the LODESTAR GS.

Parameter	**Average Value**
Effective Isotropic Radiated Power (EIRP)	-0.80 dBW
Received Frequency	468.5 MHz
Received Isotropic Power	-152.12 dBW
Carrier-to-Noise-Density Ratio (C/No)	59.80 dB-Hz
Bandwidth	15.00 kHz
Carrier-to-Noise Ratio (C/N)	18.70 dB
Energy per Bit to Noise Ratio (Eb/No)	15.80 dB
Bit Error Rate (BER)	4.9e-16

The results presented in Table 4 demonstrate a good communication performance and validate the robustness of the proposed link. The C/No value of 59.80 dB-Hz is significantly high, indicating a well received signal quality. Consequently, the carrier-to-noise ratio (C/N) of 18.70 dB and the energy per bit to noise power spectral density ratio (Eb/No) of 15.80 dB comfortably exceed the thresholds required by most modulation and coding schemes to ensure low-error communication. The resulting bit error rate (BER) confirms that the link can be established, ensuring the integrity of the scientific and telemetry data transmitted by the satellite. The positive link margin, implicit in these results, provides resilience against atmospheric variations and other sources of degradation, thus consolidating the feasibility of the communication architecture to meet the mission's requirements.

4 Conclusions

This paper presented the preliminary mission analysis for the Perceive satellite, confirming the feasibility of its proposed architecture for monitoring the Cerrado biome. The analysis validated the selection of a Sun-Synchronous Orbit (SSO), which ensures launch accessibility and compliance with orbital debris regulations. Furthermore, the communication link budget demonstrated a robust performance with significant margins, guaranteeing reliable data transmission. In summary, the key operational aspects of the mission were successfully validated, providing a solid technical foundation for the development of the Perceive satellite.

4.1 Declaration of Competing Interest

The authors declare no conflict of interest.

4.2 Fundings

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