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Design, Implementation, and Flight Validation Strategy of AkSat U2 and ViskanSat Sub-Orbital Picosatellite Platforms aboard the Rhumi-1 Sounding Rocket

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Abstract: This study presents the design rationale, subsystem implementation, and comparative evaluation of two sub-orbital picosatellite demonstrators, AkSat U2 and ViskanSat, developed as ultra-compact, low-cost platforms for near-space technology validation aboard the Space Zone Aerospace's Rhumi-1 sounding rocket. Both systems employ an identical mechanical form factor, avionics architecture, and power subsystem to enable controlled performance comparison under the same flight conditions. Each demonstrator integrates a 3D-printed structural enclosure, an ESP32-based microcontroller, a high-resolution MS5611 barometric pressure sensor, and an MPU6050 inertial measurement unit to support autonomous data logging of altitude, inertial dynamics, and thermal variations during ascent, coast, and descent. The Rhumi-1 sub-orbital trajectory, reaching altitudes of approximately 30–75 km, provides a relevant test environment for evaluating sensor fidelity, structural robustness, and low-power operational strategies under rapidly changing atmospheric and dynamic conditions. Pre-flight characterization and comparative analysis indicate strong performance consistency between the two platforms, demonstrating manufacturing repeatability and subsystem reliability. The results reinforce the effectiveness of low-cost picosatellite demonstrators as scalable technology-readiness tools for future balloon-borne, aerial, and femtosatellite orbital missions.

Table of Contents

1. Introduction

The rapid evolution of miniature electronics, additive manufacturing, and open-source embedded software has reshaped access to space technology [1,2]. Picosatellites spacecraft with masses below 100 g represent the extreme end of this miniaturization trend, enabling cost-efficient experimentation, technology validation, and educational missions. Unlike conventional nanosatellites, picosatellites emphasize architectural simplicity, reproducibility, and rapid iteration. AkSat U2 and ViskanSat were conceived as twin demonstrator platforms to support near-space experimentation using sub-orbital launch vehicles [3]. By maintaining identical system configurations, the mission adopts a comparative engineering methodology, allowing sensor consistency, avionics stability, and structural integrity to be evaluated under identical environmental exposure. Such an approach aligns with modern femtosatellite development strategies, where sub-orbital testing acts as a bridge between laboratory validation and orbital deployment.

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2. Role of Sub-Orbital Flights in Miniature Satellite Development

Sub-orbital missions provide access to dynamic flight environments that cannot be replicated fully through ground testing. During ascent and descent, payloads experience [3, 4]:

- High transient acceleration loads
- Rapid atmospheric pressure reduction
- Strong thermal gradients
- Short-duration microgravity conditions
- Aerodynamic instabilities during descent

These conditions offer a valuable opportunity to verify avionics behavior, sensor accuracy, and mechanical survivability before committing to higher-cost missions such as high-altitude balloon campaigns or orbital launches [4, 5].

3. The Rhumi-1 Sounding Rocket as a Test Platform

Rhumi-1 is a micro-payload sounding rocket designed to support academic and early-stage research missions. Depending on configuration, it achieves sub-orbital apogees ranging from approximately 30 km to 75 km. Its payload compartment provides mechanical protection and thermal buffering while allowing pressure equalization through venting pathways. AkSat U2 and ViskanSat were tailored to fit within Rhumi-1's modular payload bay. The vehicle's acceleration environment (exceeding 10 g), short mission duration, and controlled recovery profile make it suitable for validating pressure sensors, inertial measurement units, and low-power embedded systems [3].

4. Mission Objectives and Expected Flight Profile

The sub-orbital mission aims to validate the performance of barometric and inertial sensors during both ascent and descent phases, examine the structural response of additively manufactured enclosures under flight conditions, and assess the endurance of the power subsystem during duty-cycled operation. In addition, the mission seeks to demonstrate autonomous onboard data logging without any ground intervention and to compare identical payloads exposed to the same flight environment to evaluate consistency and reliability.

Table-1 Mission Objectives and Description of AkSat U2 and ViskanSat

Objective Area	Description
Sensor Validation	Validate the performance of barometric and inertial sensors during ascent and descent
Structural Evaluation	Examine the structural response of additively manufactured enclosures under flight conditions
Power Subsystem Assessment	Assess the endurance of the power subsystem during duty-cycled operation
Autonomous Operation	Demonstrate autonomous onboard data logging without ground intervention
Payload Comparison	Compare identical payloads exposed to the same flight conditions

Table-2 Expected Flight Dynamics of Rhumi-1 Launch Vehicle [3]

Phase	Description	Expected Conditions
Boost	0-1 seconds	High thrust, 8-12g acceleration
Ascent	1-50+ seconds	Rapid pressure drops, temperature gradients
Coast	Near apogee	Low dynamic pressure, microgravity margins
Descent	Parabolic fall	Aerodynamic oscillation, rising thermal loads
Recovery	Final stage	Subsystem shutdown

Pressure levels during ascent are expected to drop to a few kilopascals, providing a useful calibration range for high-resolution barometric sensors.

5. Mechanical and Structural Design

5.1 Form Factor and Materials

Both picosatellites employ a compact cubic form factor measuring approximately 50 mm × 50 mm, with a total mass below 100 g. The external shell is fabricated using fused deposition modeling (FDM) with PLA filament. This choice balances structural rigidity, mass efficiency, and rapid manufacturability [7,8]. The mechanical specifications of both the satellites are provided in the table below:

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Table-3 Mechanical Specifications of the Picosatellite Demonstrators

Parameter	**Value**
Dimensions	50 mm x 50 mm x 48mm
Mass	<100 g
Material	PLA (Shell), FR4 (Internal)
Max Withstood Acceleration	15 g
Wall Thickness	1.8 mm
Mount Points	Four-point frame attachment

5.2 Internal Architecture

Electronics are mounted on stacked FR4 plates housed within the printed enclosure. This layered configuration minimizes relative motion between components and distributes mechanical loads during launch vibration. Fastened interfaces between the enclosure and internal plates provide repeatable alignment [7,8].

5.3 Structural Qualification

Finite element simulations and vibration testing indicate that the enclosure experiences stresses well below the material yield limit during expected launch loads. Experimental vibration sweeps confirmed that no mechanical loosening or component displacement occurred [7,8].

Figure-1 ESP32, MPU6050 Sensor, and Battery Integrated to AkSat U2

6. Avionics and Electrical Architecture

6.1 System Overview

Each picosatellite integrates the following core subsystems:

- ESP32 microcontroller unit
- MS5611 barometric pressure sensor
- MPU6050 six-axis inertial sensor
- Lithium-polymer battery with regulation
- Non-volatile onboard data storage

6.2 Microcontroller Selection

The ESP32 platform was selected due to its balance of processing capability, peripheral support, and low-power operating modes. Features such as deep sleep functionality and flexible I/O interfaces make it suitable for short-duration sub-orbital missions with constrained energy budgets [9].

6.3 Sensor Payload

The MS5611 barometric sensor provides high-resolution pressure measurements suitable for altitude reconstruction in near-space conditions. The MPU6050 IMU records linear acceleration and angular rate data, enabling analysis of launch dynamics and descent behavior [10].

7. Firmware Design and Data Management

7.1 Software Architecture

The onboard firmware is implemented in MicroPython, enabling rapid development and modular code structure. The software sequence includes system initialization, sensor stabilization, periodic data acquisition, storage routines, and safe shutdown handling [10].

7.2 Power-Aware Operation

To maximize battery endurance, the system operates in a duty-cycled mode. The microcontroller wakes at predefined intervals, powers the sensors, records measurements, and returns to deep sleep. Sampling intervals between 2 and 5 seconds were selected to balance temporal resolution with energy consumption [11].

7.3 Data Logging

All sensor outputs are stored locally in timestamped records, including pressure, derived altitude, acceleration, angular velocity, and temperature. This approach eliminates dependence on real-time telemetry and ensures data integrity even in the event of communication loss [12].

Figure-2 3D printed AkSat U2 Picosatellite Bus

8. Power Subsystem and Budget

A compact lithium-polymer battery supplies regulated power to all subsystems. Under active conditions, total current consumption remains below 100 mA, while deep sleep reduces draw to the microampere range. Duty-cycling extends operational lifetime well beyond the mission duration, providing margin for pre-launch delays [12].

9. Ground Testing and Calibration

Prior to flight integration, both platforms underwent:

- Vibration testing across low-frequency launch-relevant bands
- Thermal cycling between moderate temperature extremes
- Sensor calibration at known pressure and orientation references

Calibration results confirmed minimal offset differences between the two units, supporting their use in comparative performance analysis.

10. Comparative Evaluation of AkSat U2 and ViskanSat

Despite identical designs, minor variations were observed due to manufacturing tolerances and component-level differences. Pre-flight measurements indicate close alignment in pressure offset, inertial noise, and battery capacity, with all deviations remaining within acceptable engineering margins. The comparative approach validates not only subsystem performance but also the reproducibility of low-cost picosatellite manufacturing workflows.

11. Applications and Future Development

The demonstrated architecture supports a wide range of future applications, including atmospheric profiling using balloon or UAV platforms, educational space engineering missions, femtosatellite technology demonstrators, and autonomous environmental sensing payloads. Planned upgrades to the system include the integration of telemetry downlinks, enhanced data compression techniques, solar-assisted power systems, and radiation-aware component selection to improve reliability and mission capability.

12. Conclusion

The AkSat U2 and ViskanSat picosatellite demonstrators successfully completed their intended sub-orbital mission objectives aboard the Rhumi-1 sounding rocket, validating the performance of identical low-cost spacecraft architectures under realistic near-space flight conditions. Both platforms operated nominally throughout the ascent, coast, and descent phases, enabling the continuous collection of atmospheric pressure, derived altitude, inertial motion, and temperature data in parallel with flight time. The synchronized datasets obtained from the two satellites demonstrate consistent altitude profiling and dynamic response, confirming reliable sensor operation and stable avionics behavior under rapidly changing pressure and acceleration environments. Comparative analysis indicates strong agreement between corresponding measurements from both platforms, reinforcing design repeatability and manufacturing robustness. The successful acquisition and post-flight analysis of time-correlated atmospheric and flight data highlight the effectiveness of compact picosatellite demonstrators as practical tools for sub-orbital experimentation and technology readiness advancement. These results support the scalability of the demonstrated architecture toward future near-space, balloon-borne, and femtosatellite missions, where low mass, low cost, and autonomous data collection remain critical design drivers.

Figure-3 Post Launch Event Image with Mr. Ramesh Kumar (Founder, Grahaa Space); Dr.Mylsamy Annadurai (Ex-ISRO Director); Mr. Anand Megalingam (CEO, Space Zone India); Mr.Manimaran VS (MD, Viskan Groups); Mr.Aparajith BSM (Director, Grahaa Space).

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14. Conflict of Interest

The author declares no competing conflict of interest.

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