2024 13th International Conference on Renewable Energy Research and Applications (ICRERA) | 979-8-3503-7558-9/24/$31.00 ©2024 IEEE | DOI: 10.1109/ICRERA62673.2024.10815125

In-orbit Performance Evaluation of the MDASat-1 CubeSat Power System

Sinamandla Maqina
Africa Space Innovation Centre
Cape Peninsula Univ. of Technology
Bellville, Cape Town, South Africa
MaqinaS@cput.ac.za

Lilie Leopold-Kateya
Africa Space Innovation Centre
Cape Peninsula Univ. of Technology
Bellville, Cape Town, South Africa
LeopoldL@cput.ac.za

Royi Nyameko
Africa Space Innovation Centre
Cape Peninsula Univ. of Technology
Bellville, Cape Town, South Africa
Royin@cput.ac.za

Innocent E. Davidson
French-South African Institute of Technology/Africa Space Innov. Centre
Cape Peninsula Univ. of Technology
Bellville, Cape Town, South Africa
Davidsoni@cput.ac.za

Ayodele Periola and Ayodele Ayeleso
Department of Electrical, Electronic and Computer Engineering
Cape Peninsula Univ. of Technology
Bellville, Cape Town, South Africa
PeriolaA@cput.ac.za

Gunjan Gupta
Department of Electrical, Electronic and Computer Engineering
Cape Peninsula Univ. of Technology
Bellville, Cape Town, South Africa
guptag@cput.ac.za

Vipin Balyan
Department of Electrical, Electronic and Computer Engineering
Cape Peninsula Univ. of Technology
Bellville, Cape Town, South Africa
BalyanV@cput.ac.za

Janvier Kamanzi
Department of Electrical, Electronic and Computer Engineering
Cape Peninsula Univ. of Technology
Bellville, Cape Town, South Africa
kamanzij@cput.ac.za

Oluwaseyi Babalola
Department of Electrical, Electronic and Computer Engineering
Cape Peninsula Univ. of Technology
Bellville, Cape Town, South Africa
BABALOLAO@cput.ac.za

***Abstract*—In recent years, South Africa has increasingly leveraged space-based technologies to enhance national resource management and strengthen its security capabilities. As the nation transitions to a digital economy, space science and technology (SST) has become a vital component, particularly in remote sensing applications, including weather monitoring, renewable energy (solar and wind), communications, resource management, and the exploration of inaccessible areas. This evolving landscape drives ongoing research at the Cape Peninsula University of Technology (CPUT), with a particular focus on nanosatellite development for remote sensing. This paper presents case studies from the MDASat-1 mission, demonstrating the practical implementation and testing of nanosatellite systems at CPUT. Using whole orbit data recorded on 1 September 2024, this analysis highlights the mission's contribution to advancing space technologies for societal benefits, with the power system performing nominally during the mission.**

Keywords— CPUT, MDASat-1, Nanosatellite, Remote sensing, Renewable energy, Resource management, Space.

I. Introduction

These past five decades have demonstrated that every facet of human advancement is woven around a sound and stable energy and communications infrastructure. Space Science and Technology research is a matter of national security and priority with a focus on addressing the needs of the South African government and local industry. Operation Phakisa is a program initiated by the South African government aimed to accelerate the implementation of critical solutions that address issues highlighted in the National Development Plan (NDP). The initial phase of Operation Phakisa focuses on the South African ocean economy and is further divided into four key areas, one of which places a strong emphasis on Marine Protection Services and Governance [1]. It was projected between 2008 and 2009, that the future South African space industry would offer a unique opportunity to increase the number and interest of students in master's degree focusing on satellite engineering and encourage young graduates to further their academic knowledge in space sciences.

Specifically, the establishment of SANSA in 2010 reaffirmed and acknowledged the shortage of space and aerospace engineering skills in South Africa. Therefore, Cape Peninsula University of Technology (CPUT) is closely aligned with the national agenda as it addresses human capital development (HCD) for the sector.

A. Background of the CPUT Missions

Since the late 1990s, when the concept of nanosatellite was developed, there has been a growing interest from both the academic and commercial sectors in nanosatellite technologies. The number of nanosatellites launched to date and the launch forecast, as shown in Fig. 1, serve as evidence. This is due to the reduced complexity and cost. A nanosatellite implies a spacecraft that weighs between 1 and 10 kg while a CubeSat is a subset of the nanosatellite that uses a standardised form factor ranging from 1U to 16U [14]. CPUT has adapted the CubeSat format to develop a few satellites for human capital development and technology demonstration.

For instance, the Africa Space Innovation Centre (ASIC) at CPUT started the development of ZACUBE-1, as an input to the HCD deficiency that was identified during the establishment of SANSA. The primary payload of ZACUBE-1 was for the SANSA's Hermanus Magnetic Observatory (HMO) [3].

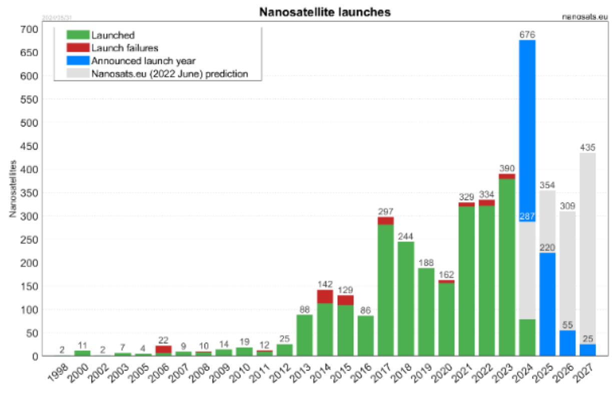


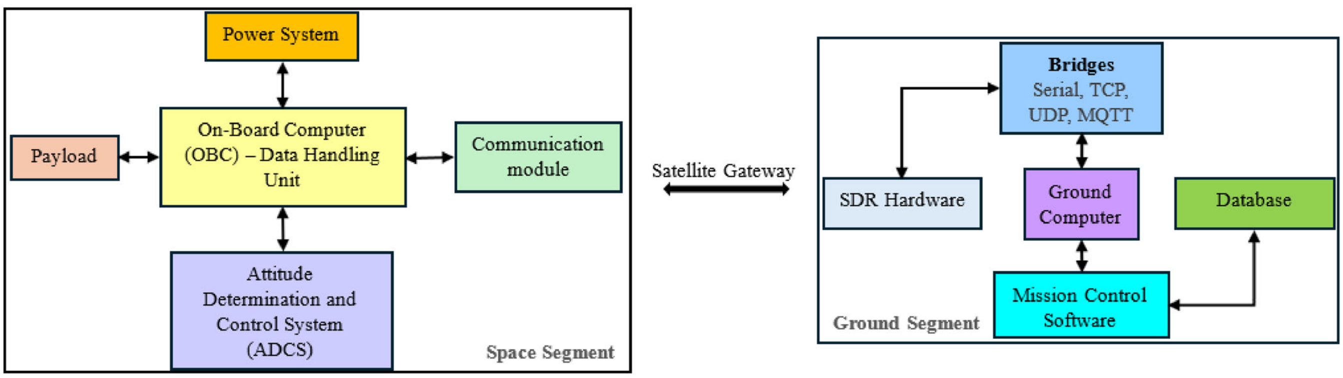
Fig. 1. Nanosatellite launches [15]

Furthermore, ASIC proposed the development of space-based technical solutions to augment the maritime domain awareness (MDA) program of the South African government. This applies to South Africa's exclusive economic zone. Consequently, ZACube-2 was developed as the inaugural mission to validate technologies for the MDA. Launched in 2018, the nanosatellite represented a precursor mission for an ambitious constellation of nanosatellites. ZACUBE-2 mission's Primary Payload, a software-defined radio (SDR), was used to receive the transmitted automatic identification system (AIS) messages from low earth orbit (LEO).

Additionally, ZACUBE-2 hosted a secondary payload known as the imager, which was used as a technology demonstrator and to increase the Technology Readiness Level (TRL) of the design. The imager consists of two near-infrared sensors each fitted with a different light filter. The two sensors cover the same area on the earth's surface and are synchronised to capture images at the same time [6]. As a result of the success of the technology demonstrator mission of ZACUBE-2, CPUT embarked on a mission to evaluate the possibility of launching a constellation using three satellites. This constellation was launched on 13 January 2022 as the MDASat-1 mission. New features were implemented in the new AIS payload e.g. over-the-air upgrades, long-range AIS, to capture raw data, and a more efficient messaging scheme [5][7].

This paper presents a comprehensive analysis of the significant contributions made by ASIC at CPUT in the field of nanosatellite development. ASIC has been at the forefront of advancing space technologies, particularly through the design and deployment of nanosatellites with versatile applications, including the monitoring of maritime traffic, wind energy potential, ocean currents, and wave dynamics. These capabilities are of critical importance for South Africa's growing reliance on space-based systems to address national resource management and security needs.

Fig. 2. Elements of space system



A key focus of this work is the detailed performance analysis of the power system onboard the MDASat-1 nanosatellite, a primary satellite in the ASIC portfolio. The power system's efficiency and stability are vital for ensuring the sustained operation of satellite sensors and communication systems, particularly in harsh space environments. By leveraging real-time orbit data, this paper evaluates the robustness and reliability of the power system under various operational conditions. The findings not only underscore the satellite's performance but also highlight the potential for further enhancements in power management for future satellite missions.

B. *Overview of the Space System*

The space system consists of various elements that are put together to achieve a specific space mission objective. This system can be categorised into three main segments: space, launch, and ground [8]. Fig. 2 shows the fundamental components of the space and the ground segments.

1) The Space Segment: The space segment is comprised of at least a single satellite, which carries a payload(s) that accomplishes the primary mission objectives including the bus that hosts other major subsystems such as the electric power system, attitude control system, communication system, and on-board computer [8] [9] [10]. These subsystems are discussed as follows.

- *Power System:* The power system is made up of three main components: solar panels, batteries, and an electrical power system (EPS). This system generates power from solar panels and uses batteries as an onboard storage facility. The EPS conditions and distributes the bus voltage into a network of regulated and unregulated supplies for all the onboard electronics [10].
- *Communication System:* The communication system is one of the most important components of satellites. It enables the transfer of information between the satellite and the ground station [10].
- *On-board Computer:* The on-board computer (OBC) is the unit where flight software is implemented. Various functions are implemented for telecommand execution, housekeeping telemetry gathering, formatting and storage, time synchronisation, watchdog timer reset, time event scheduling, etc.

  Also, the OBC provides storage (memory) for different data loggers while controlling other subsystems through the I2C or SPI interface [8] [10].
- *Payload:* The payload performs a specific function that delivers the primary mission objectives [8] [10]. It can be commanded or controlled from the ground and results are transferred to the data handling device on board the satellite before they are relayed to the ground station. One example of a payload is an automatic identification system (AIS) receiver that receives AIS messages transmitted by maritime traffic monitoring vessels.

2) The Launch Segment: The launch segment is normally obtained through a brokerage service; thus, it is not covered in this paper.

3) The Ground Segment: The ground segment is made up of the ground computer, SDR, mission control software (MCS), databases, antenna, and antenna controllers [5][7]. Each of these is discussed as follows.

- *Ground Computer(s):* The ground computer is used for several functionalities such as debugging, and hosting of a variety of applications that include mission control software, virtual machines, and databases.
- *Software Defined Radio:* SDR platforms offer significant flexibility and versatility due to their reconfigurable nature [5]. Examples of commercially available SDR hardware include the ADALM-PLUTO, Ettus USRP boards, LimeSDR Mini 2.0, and FunCube Dongle Pro Plus. These hardware platforms are supported by a variety of software packages, such as SDR#, MATLAB, GNURadio Companion, and Python, which can be utilized across different operating systems including Windows and Linux.
- *Mission Control Software:* The MCS integrates the processes required for the monitoring, control, and automation of the satellite, providing an intuitive application for operators during mission control. For mission monitoring, telemetry data is requested and evaluated against database specifications to generate alarms triggered by events, visualize telemetry, and send notifications. Overpass management is facilitated through automation processes that handle downloads, monitor onboard channel storage usage, and manage scheduling tasks. Additionally, the MCS can control ground resources such as radio controllers and antenna controllers [11].
- *Database*: Databases are used for data processing and storage. They contain conversion tables that process downloaded raw frames and distribute them to various systems of the ground station infrastructure [11].

II. MDASat-1 In-Orbit Power Analysis

This section analyses the performance of one of the MDASat-1 CubeSats power systems in orbit. The spacecraft has a 2U form factor and is fitted with body-mounted solar panels on all facets except the Nadir-facing side. Table 1 below shows the rated idle and peak power consumption of each subsystem on MDASat-1. The subsystems that are currently active are the UTRXC, OBC, EPS, and the battery module. The HSTXC is currently idling, and the deployed antennas' electrical circuit is off. The UTRXC, OBC, and HSTXC are powered by the bus voltages – 3.3V, 5V, and BATV for the OBC.

TABLE I. MDASat-1 Subsystems Power Consumption

Sub-system	Power consumption (W)	
	Idle	***Peak***
HSTXC	0.05	5
UTRXC	0.22	5.1
EPS Motherboard	0.2	0.2
30Wh Battery	0.3	0.3
OBC	0.41	0.61
Deployable Antenna	0	1.85
ADCS	0.57	2.3
Payload SDR	0	5

1) Mode of Operation: The performance analysis of the MDASat-1's power systems takes into account the average power consumption of the subsystems that are always switched on during the mission. The ADCS is currently configured in Y-Thomson spin as shown in Fig. 3; the UTRXC HK beacon is only switched on when the satellites fly overhead the ground station, and only the status inactivity beacon is transmitted every 5 minutes. This can also be disabled through the I2C command. The OBC manages the whole orbit data, event logs, time scheduling, and data logging. TT&C is managed through the CPUT's ground infrastructure, which supports a wide range of frequencies from VHF to S-Band. The station has been instrumental in supporting mission control operations for ZACube-1, ZACube-2, and MDASat-1. There are plans to extend these operations to include M2MSat-1, which is currently under development.

Fig. 4 illustrates the mast of the commercial ground station located at the Bellville campus in Cape Town, South Africa. The ground station supports 1.2 kbps AFSK and 9.6 kbps GMSK for both uplink and downlink communications. It can also handle data rates of up to 8 Mbps QPSK/OQPSK downlink from the HSTXC.

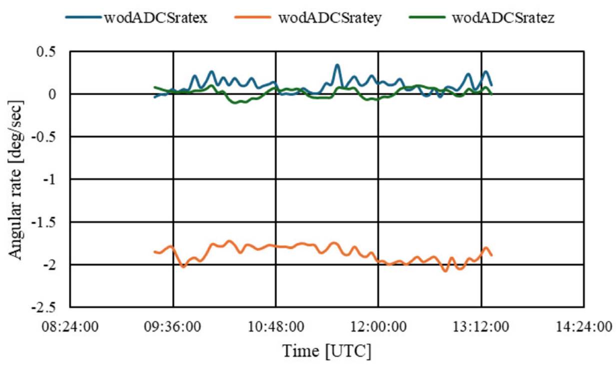


Fig. 3. MDASat-1 Y Thomson spin: reference value is -2 deg/sec

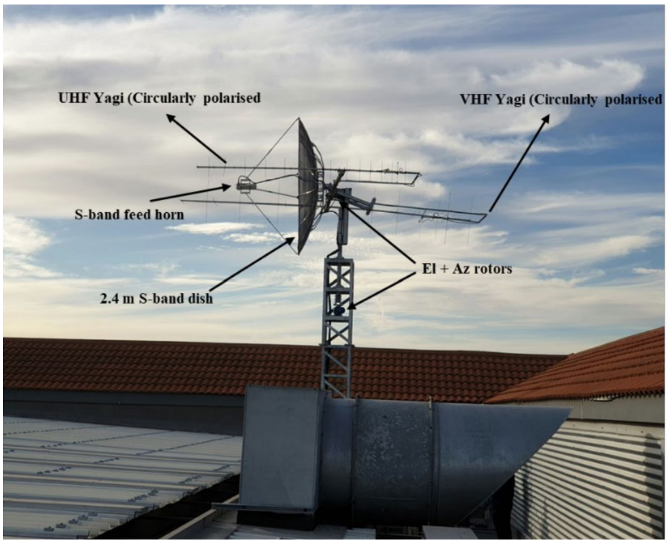


Fig. 4. CPUT ground station with S-band antenna in a parked position

This study examines two distinct operational scenarios for the satellite: sunlight exposure and eclipse conditions. The analysis focuses specifically on the battery's charge and discharge cycles, which are critical for maintaining the satellite's functionality. The battery reaches its end-of-charge voltage at 8.26 V, while full discharge occurs at 6.2 V. A safeguard is in place whereby, if the battery voltage drops below 7 V, all subsystems are automatically powered down to prevent excessive depletion and allow the battery to recover.

During eclipse periods, when the satellite is in Earth's shadow, the solar panels cease to generate power, leaving the satellite entirely reliant on its battery reserves. This operational behaviour is corroborated by the battery's current direction indicator, which displays a value of 1 during charging and a value of 0 during discharge. These insights into battery performance and power management are crucial for understanding the satellite's operational resilience, particularly in energy-limited conditions such as extended eclipses.

III. RESULTS AND DISCUSSION

Fig. 5 shows a plot of the battery current direction, 2U solar panel voltage, and the battery voltage. From the figure, it can be seen that the battery levels change based on whether the battery is charging or discharging and its operating nominal. As expected, the 2U solar array is not generating a voltage when in eclipse and the current direction is equal to 0 during this period, indicating that the battery is discharging.

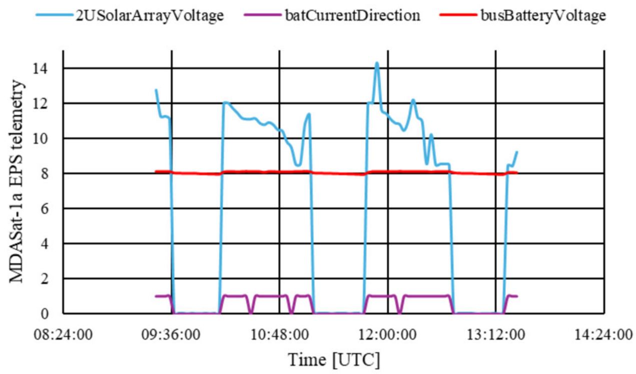


Fig. 5. EPS telemetry showing voltage level when spacecraft is in sunlight or eclipse

Fig. 6 shows the power consumption of the ADCS unit. This unit is powered by three power distribution modules − BATV, 5V, and 3.3V. Power from each module is illustrated in the figure as well as the combined consumption. It should be noted that the ADCS wheel is currently switched off. The average power is equal to 0.63W.

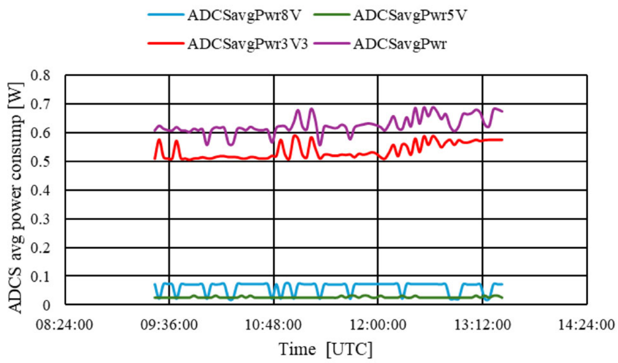


Fig. 6. ADCS power consumption

Fig. 7 shows the bus power consumption. The data presented in this paper is generated from the whole orbit data (WOD) sampled at 2 minutes intervals. It was not possible to obtain the power consumption during the UTRXC transmission. These values can be read directly during overpass because the transmission might fall outside the sampling interval. The current drawn from the 5V bus is approximately 850 mA.

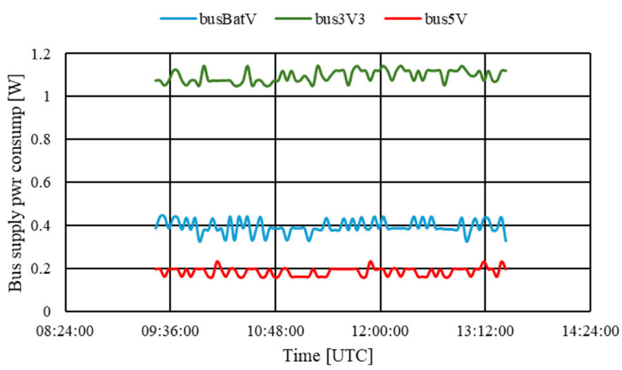


Fig. 7. Bus power consumption

IV. Conclusion

The vision of ASIC F'SATI is to establish a leading African hub for innovation and support in nanosatellite technology. This entails comprehensive capabilities in designing, implementing, and manufacturing nanosatellites, subsystems, and components, as well as managing space operations and providing ground-based support. The institute is actively engaged in data acquisition and management, offering satellite-based solutions tailored to address Africa's socio-economic needs. Applications include marine vessel tracking, wildfire detection, smart grid design, solar power systems, space weather research, wind and wave energy, ocean currents analysis, and technology validation and communications.

The MDASat-1 flight models were launched in January 2022. Figures presented show that the system bus voltages are nominal, and the battery voltage is kept charged to a level greater than 8V. Unfortunately, this mission payload SDR had issues with the interface; no AIS messages were received by these units. The successor mission, the M2MSat-1, will address the I2C issue, and a secondary interface through SPI will be provided.

Acknowledgment

The authors wish to acknowledge the generous support and funding from CPUT Executive Management, Directorate of Research, the Faculty of Engineering and the Built Environment, Science and Innovation Department (DSI), Trade, Industry and Competition Department (DTIC), South Africa National Space Agency, National Research Foundation (NRF), Technology Innovation Agency (TIA), Council for Scientific and Industrial Research (CSIR), University of Stellenbosch, CubeSpace, Cubecom, Stone Three and Astrofica

References

[1] Operation Phakisa, [online] Available: http://www.operationphakisa.gov.za/operations/oel/pmpg/pages/default.aspx.

[2] W. H. Steyn, R. van Zyl, M. Inggs, P. J. Cilliers, "Current and future small satellite projects in South Africa," In: 2013 IEEE International Geoscience and Remote Sensing Symposium - IGARSS; 2013; Melbourne, VIC, Australia: 1294–1297.

[3] R.R. van Zyl, D. F. Visser, P. J. Cilliers, and B. D. L.Opperman, "ZACUBE-1 space weather mission: Characterize the SuperDARN HF Radar antenna array at SANAE-IV", Space Weather, Vol. 11, pp. 1–3, oi:10.1002/swe.20018, 2013.

[4] P. J. Cilliers, D. Agaba, M. Inggs, and R. van Zyl, "Calibration of a superDARN radar antenna by means of a satellite beacon on a CubeSat", In: 2013 IEEE International Geoscience and Remote Sensing Symposium - IGARSS; 2013; Melbourne, VIC, Australia: 1290–1293.

[5] D. de Villiers and R. van Zyl, "ZACube-2: The successor to Africa's first nanosatellite," 2015

[6] Cogan, D., Griffith, D. J., E. Magidimisha, and R. Van Zyl, "Flight hardware verification and validation of the K-line fire sensor payload on ZACube-2", In: Proceedings of the 5th Conference on Sensors, MEMS and Electro-Optical Systems (SMEOS) Skukuza, South Africa, 8-10 October 2018.

[7] N. Royi, "The South African Maritime Domain Awareness Satellite Constellation and Beyond," 2022 International Conference on Electromagnetics in Advanced Applications (ICEAA), Cape Town, South Africa, 2022, pp. 380-380, doi: 10.1109/ICEAA49419.2022.9899898.

[8] J. Wertz, and W. Larson, "Space Mission Analysis And Design. 3rd ed. Torrance, California: Microcosm, 1999.

[9] NASA, "NASA Systems Engineering Handbook," NASA SP-2016-6105 Rev2, 2016.

[10] The CubeSat Program, Cal Poly SLO, "CubeSat Design Specification," 1U-12U CP-CDS Rev. 14.1, 2022.

[11] G. Naidoo, R. van Zyl, and G. Gupta, "ZACube-2 Mission Operations Analysis," In: Kumar, A., Gunjan, V.K., Hu, YC., Senatore, S. (eds) Proceedings of the 4th International Conference on Data Science, Machine Learning and Applications. ICDSMLA 2022. Lecture Notes in Electrical Engineering, vol 1038. Springer, Singapore. https://doi.org/10.1007/978-981-99-2058-7_24

[12] French South African Institute of Technology website, https://blogs.cput.ac.za/fsati/products/, Last accessed: August 22, 2023.

[13] European Cooperation for Space Standardization, "System engineering general requirements," ECSS-E-ST-10C Rev.1, 15 February 2017.

[14] J. Groh. "What are SmallSats and CubeSats?" nasa.gov. Accessed: Jul. 6, 2024. [Online]. Available: https://www.nasa.gov/what-are-smallsats-and-cubesats/

[15] E. Kulu "Nanosats Database." nanosats.eu. Accessed: Jul. 6, 2024. [Online]. Available: https://www.nanosats.eu/#figures