UTILIZING UGANDA'S FIRST SATELLITE TO FULFILL ITS DEMANDS.

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The Joint Global Multi-National program, legendarily known as BIRDS, is a multinational small satellite project conceptualized in 2015 by the Kyushu Institute of Technology (Kyutech), Japan. The BIRDS program aims to provide opportunities to non-spacefaring countries to design, integrate, test, launch, and operate their country's first satellite.

This paper focuses on the first satellite for Uganda named PearlAfricaSat-1 and how its missions will solve the problems that the citizens are facing. In 2020, the government of Uganda sent three graduate engineers to Kyutech to design, build, test, launch, and operate Uganda's first satellite. Uganda joined the BIRDS-5 satellite project with specific missions guided by the needs of their citizens that include but are not limited to agricultural enhancement, climate and disaster management, natural resources management, utilities, and infrastructure management. PearlAfricaSat-1 was then developed to execute several missions, including on-board image classification, performance characterization of a passive attitude control system, a store-and-forward mission for remote data collection, and a demonstration of the use of three Raspberry Pi Zero in CubeSats. Specifically, a demonstration of a multispectral imaging system using a commercial off-the-shelf image sensor to capture images of the country at specific wavelengths to facilitate analysis of water quality, soil fertility, and land use and cover. The satellite will then be launched and deployed from the International Space Station in October and November 2022, respectively. This paper describes the path towards Uganda's first satellite, PearlAfricaSat-1, its core missions, and lessons learned. The last part of this paper will talk about how important Uganda's first satellite is to its people, since Uganda has never been in space before.

Key Words: Uganda's First Satellite – Its Significance – Lessons Learnt

1. Introduction

The Joint Global Multi-National program, legendarily known as BIRDS, is a multinational small satellite project conceptualized in 2015 by the Kyushu Institute of Technology (Kyutech), Japan. The BIRDS program aims to provide opportunities for non-spacefaring countries to design, integrate, test, launch, and operate their country's first satellite. The primary goals of the BIRDS program are capacity building [1] and taking the first step towards an indigenous space program for each country by effectively building and operating the first satellite of their nation.

Uganda a non space faring county lies astride the equator within the East African region and is located between longitude 30° and 35° east of Greenwich. The country stretches from 4° north to 1.5° south of the equator. Uganda, as one of only a few equatorial republics, is conveniently situated as a launch site to launch satellites into geostationary orbit. Even though the government wants to develop space science and technology [2], this opportunity has never been explored and is still untapped.

Uganda`s journey into space started in 1968 when the country assented to the Outer Space Treaty on April 24, 1968. With this, Uganda went ahead and established earth satellite stations for telephone and television broadcast at Ombachi in Arua and Mpoma in Mokono in 1976 and 1978, respectively [3]. However, all these stations were relying on satellites of other countries for their operations and there were questions of data security, service reliability, high operational costs, and lack of sustainability plan. Currently, all these facilities are non-functional, dilapidated, and decommissioned. To date, there is no attempt to revamp these facilities.

By and large, Uganda did not harness the opportunities and capabilities that Space Science and Technology offer until April 2020, when the government, through the Ministry of Science, Technology, and Innovation (MoSTI), presented three graduate engineers to Kyutech to undergo capacity development to design, build, test, launch, and operate Uganda's first satellite. This followed the guidance of His Excellency the President of the Republic of Uganda to MoSTI titled "Guidance to the Science, Technology, and Innovation Sector" dated March 24, 2017, which provided several interventions and areas on which the Ministry should focus on, one of which was to establish a Space Agency and a Space Institute to explore the country's options and capabilities in space.

Figure 1: Uganda's Space Engineers: Edgar MUJUNI (Left), Bonny OMARA (Center) and Derrick TEBUSWEKE (right).

After presenting the engineers to Kyutech, the Ministry conducted countrywide consultations with other Ministries, Departments, and Agencies (MDAs), universities and research institutions, development partners, private sectors, local governments, and individuals, among others, to assess the needs of the country, society, culture, and stakeholders to be addressed by the first satellite.

The outcome of the consultation uncovered the challenges and needs of the stakeholders and the priority areas as shown in Table 1 for which the first satellite was fashioned to address.

No	Sector	Needs
1	Food Security	Soil quality, fertility and moisture mapping, land use and cover monitoring, animal tracking, precision agriculture, tracking pests breeding pattern, accurate weather forecasting.
2	Water, Environment and Natural Resources	Management of water bodies and related natural resources, climate change loss mitigation planning, Wetland and management, air quality and pollution monitoring.
3	Disaster Management	Prediction and early warning; search and rescue operations, monitoring oil spills, landslides, droughts, fires, floods, earthquakes, hailstorms, etc.
4	Defense and Security	Monitoring border movement, surveillance of illegal activities, management of public assemblies, troop deployment and movement.
5	Minerals, Oil, and Gas	Mineral mapping and exploration, monitoring mining activities, monitoring oil and gas pipelines and facilities.
6	ICT	Internet and telecommunication services, Satellite based e-services, 4IR and Internet of things.
7	Education and Scientific Research (Academia)	Plasma Ionospheric Measurement, Tele-education, virtual classroom, teacher programs, Promotion of different physical science fields such as climate, astronomy, etc.; innovation and product development, space science and weather research, etc.
8	Health	Tele-epidemiology, Tele-medicine, provision of space-based health and environmental information, etc.
9	Tourism	Monitoring of game parks and reserves, surveillance of illegal activities, incidents, animal tracking and space tourism.
10	Urban Planning	Monitoring land use and settlement, Geo-location and Mapping, Post code and addressing system, etc.
11	Industry and Service sectors	Technology transfer, research and product development, spin-off enterprises, employment, and job creation.

To address some of these fundamental challenges, Uganda joined the BIRDS-5 project to build its first satellite while improving the standard bus system for the next satellite projects and providing continuity to the satellite development of Japan and previous BIRDS projects. On the other hand, Japan aimed to improve the space activities of non-spacefaring nations by training engineers who grasp the skills required to design, build, and test their first satellite. The engineers are empowered so that when they return to their respective countries, they can confidently build subsequent series of CubeSats and provide training to other fresh graduates, ultimately creating a sustainable space program in their respective countries.

Method of delivery of capacity development

The engineers were exposed to the complete life cycle of satellite development, from mission formulation to operation. Figure 2 displays the BIRDS-5 team, and principal investigator (PI). Based on competency, interest, and background, each student was assigned to lead the development of different subsystems while consulting with the supervisors and other project team members. There were weekly meetings set up to track each team's progress and key milestones in the project.

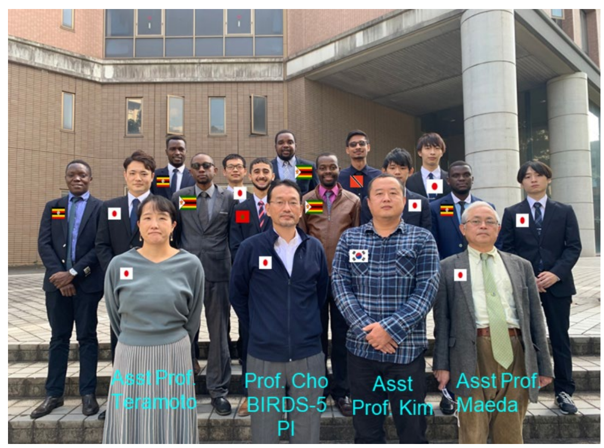

Figure 2: BIRDS-5 Team Member

BIRDS-5 SATELLITE OVERVIEW

Description of the satellite

The BIRDS-5 project is a constellation of two 1U satellites (PearlAfricaSat-1 and ZIMSAT-1) and one 2U satellite (TAKA-1). 1U CubeSats with dimensions of 100 mm x 100 mm x 113.5 mm and a weight of less than 1.33 kg, and 2U CubeSats with dimensions of 100 mm x 100 mm x 227 mm and a weight of less than 2.66 kg. External views of BIRDS-5 satellites are shown in Figure 3 with respective axis defined.

PearlAfricaSat-1, ZIMSAT-1, and TAKA-1 will execute several missions, including APRS digipeater, Store-and-Forward (S&F), Particle Instrument for Nanosatellites (PINO), Attitude Visualization, On-board Image Classification, and Multispectral Imaging. PearlAfricaSat-1 and ZIMSAT-1 have different names, but the hardware and system configurations are the same. All printed circuit boards

(PCBs) are connected to a backplane via 50-pin.

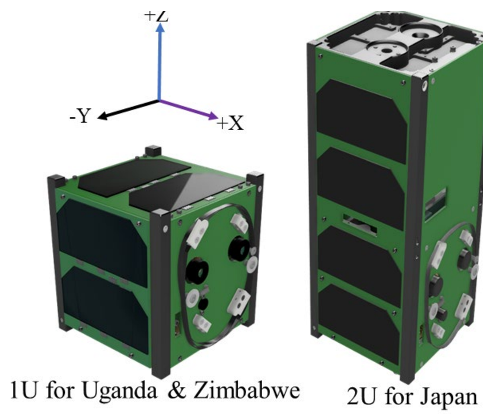

Figure 3: External view of the BIRDS-5 CubeSats

BIRDS-Bus system [4]

The BIRDS Program has been implemented by Kyutech from 2015 to 2022. To date, a total of fourteen satellites from BIRDS-1, BIRDS-2, BIRDS-3, and BIRDS-4 programs have been launched as part of the program. The most pressing concerns have been the expense and time required to build and teste the satellites. This is due to the fact that each BIRDS generation had unique missions that required a significant amount of time and resources. As a result, Kyutech made efforts to standardize the bus system, saving the proprietor's money and development time. The development of PearlAfricaSat-1 is based on the BIRDS bus because the bus system proven to work over successive generations.

The BIRDS bus is made up of seven internal boards, as shown in Figure 4: the Front Access Board (FAB), On-Board Computer and Electrical Power System Board (OBC/EPS), Communication (COM) Board, Mission Board-1 (MSN-1), Mission Board-2 (MSN-2), and Rear Access Board (RAB), and the BPB. To reduce harness, they are all connected to the Back Plane Board (BPB) through a 50-pin connector.

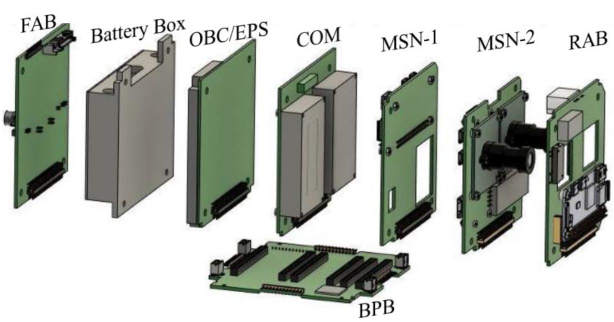

Figure 4: Standardized BIRDS-5 bus system

The FAB collects power from each solar panel, stores battery power, and protects against accidental deployment. The FAB PIC (PIC16F1789) receives commands and sends housekeeping data to the Main PIC through the UART protocol. The Main PIC collects FAB PIC data every 90 seconds in normal sampling mode and every 5 seconds during high sampling operation.

The Main PIC and the Reset PIC (Watchdog) are both included in the OBC/EPS. The main PIC (PIC18F67J94), sometimes known as the brain of the CubeSat, is responsible for processing and forwarding mission commands as well as collecting and storing housekeeping (HK) and mission data. One gigabyte of flash memory is available on the main PIC and is shared by all missions. Through the UART protocol, the main PIC and Reset PIC communicate with each other.

The COM PIC's duties include transmitting commands received from the ground station to the main PIC, creating and sending CW, and transmitting data from its flash memory to the ground station. A dipole antenna on the +X panel is used for communication with the ground station to transmit the telemetry data and CW data. Both the uplink and downlink frequencies are in the amateur band.

Data sharing from different missions to either the Main PIC or COM PIC is accomplished by the use of a share memory architect. Figure 5 depicts the shared memory block diagram. The CPLD (LC4697ZE-144TC) placed on the BPB is used by all missions to access the shared flash memory of the main PIC. The main PIC transfers the data from the shared flash to the COM flash whenever it is required by the COM PIC.

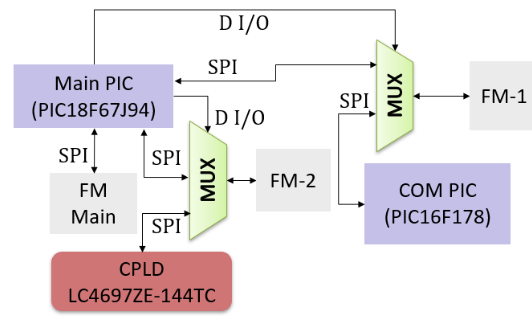

Figure 5: Shared Memory Block Diagram

The power generation is carried out via solar panels mounted on the CubeSat's five sides (-X, -Y, +Y, -Z, and +Z). Two cells are connected in series in each panel. Six rechargeable Eneloop Nickel Metal Hydride (NiMH) batteries with a capacity of 1900 mAh, assembled in a 3-series, 2-parallel configuration, are used to store the generated power. Table 1 displays the computation for electricity generation.

Table 1: Power Generation

Parameters	**Values**
CubeSat Power Generation	1436 [mW]
Energy available per one orbit	2217 [mWh]
Power loss in blocking diode	600 [mWh]
Efficiency of Electronics devices (dc/dc)	80%
Total energy available per orbit	1293.6 [mWh]

The internal interface of the CubeSat is the BPB, which is utilized to reduce the number of harnesses necessary to connect the boards. By using BPB, we can avoid failures due to misconnections or broken wires and satellite assembly is much simpler because it simply requires connecting the connectors on the board. The BPB has a CPLD (Complex Programmable Logic Device), and Mission Boss as shown in Figure 6. The CPLD is a device that can change the internal logic by software hence making Pin assignments very flexible. The mission boss on the other hand is used to enhance the integration of bus system and mission payload whenever there several missions.

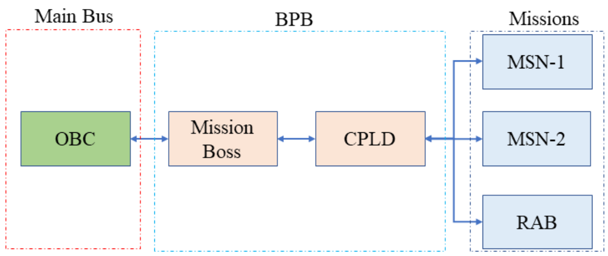

Figure 6: System Connection

PearlAfricaSat-1 Missions

All missions are handled by three mission boards (MSN-1, MSN-2, and RAB), which are interconnected to the bus system through CPLD and Mission Boss. Both are located on the BPB.

The first mission is the APRS digipeater, which relays messages from the amateur community. The second mission is called "store-and-forward," or "S&F." In this mission, the satellite gathers data from remote ground sensor terminals (GSTs), stores it, and then sends it to the ground station for further analysis, interpretation and dissemination. The third mission is BIRDS-NEST, which provides a smartphone application for sharing satellite data, satellite path, and location as well as a 3D CAD model of the satellite. Attitude Visualization (AV) is the fourth mission. It predicts the satellite's attitude by collecting and evaluating gyroscopic data and solar cell current values from the satellite. Based on the predictions provided by this mission, we send a shutter command to capture multispectral images of the target. The fifth is image classification onboard (IM-C). It takes photographs, classifies them, and stores them using machine learning techniques. The system then downlinks the images that contain the photographed object based on the results of the classification. The sixth mission is land use and cover: a COTS multispectral camera is used to acquire images of areas of interest on Earth. The images are then processed using GIS software into NDVI and utilized to investigate crop health and the area under cultivation. The eighth mission is water quality; the COTS multispectral camera is used to locate dams, lakes, rivers, and swarms as well as to determine their size using the COTS multispectral camera. The ninth mission is the determination of soil fertility. The target area on Earth is photographed using a multispectral camera. The photos collected are utilized to assess the soil's nitrogen and fertility levels. All three missions use the same multispectral camera; two multispectral cameras with different filters are used per satellite. The data collected by each camera will be used in the analysis. To control each camera, one microcontroller (MCAM-1 or MCAM-2) is installed.

PearlAfricaSat-1 Mission Design and Operation

Imaging Mission (CAM)

The camera mission is tailored to provide farmers with real-time maps to guide fertilizer use, predict crop health, and yield; give periodic maps to help with physical planning, guide the delivery of social services, resolve land disputes, enhance property tax collection; and monitor and preserve natural resources (forests, wetlands, and water bodies) in response to climate change vagaries.

The commercial-of-the-shelf camera module was selected based on its spectral response and the satellite design constraints such as its size, power requirement, and communication protocols. The Arducam OV2311 global shutter camera module with a 10-bit digital readout speed of 60 frames per second (fps) at full resolution was selected. The sensor is a monochromatic image sensor with a low voltage, high-performance with a pixel size of 3 µm x 3 µm, 1/2.9-inch CMOS sensor that provides the full functionality of a single chip 2MP with an active array size of 1600x1300. In addition, the camera is controlled by a microcontroller unit (Raspberry Pi Zero), which is responsible for communication with the OBC and saving the image on its own internal SD card (64 GB). Although the camera module includes an M12 lens with a focal length 6mm, a different M12 lens with a focal length of 12m was used to improve the GSD to satisfy the mission requirements of less tan 100m. The lens used has the specifications as shown in Table 2. Specific filters were used as required for specific applications set by the stakeholders. Based on the index database, a combination of 550 nm and 790 nm filters was selected for water quality; 680 nm and 790 nm were selected for land use and cover; and 680 nm and 720 nm for soil fertility. There needed to be a way to attach the filter, so an appropriate design was made to fit the filter into the system. The camera hardware is shown in Figure 2.

Table 2: Camera Mission Parameters

Parameters	Values
Camera Resolution	2MP
Pixel Size	3 µm x 3 µm
Focal length of the lens	12mm
FOV (D/H/V)	26°/23°/13°
Ground Swath	(164 x 132) km @400km Altitude
Ground Resolution	100m

The multispectral camera mission is executed when the camera payload receives a command from the ground station through the COM PIC and Main PIC. Imaging mission hardware is shown in Figure 4 and 5. Multispectral imagery has a relatively large file size of approximately 940kB. Hence, its software is programmed so that the original images are first converted to thumbnails and are downloaded for inspection prior to downlinking the original imagery.

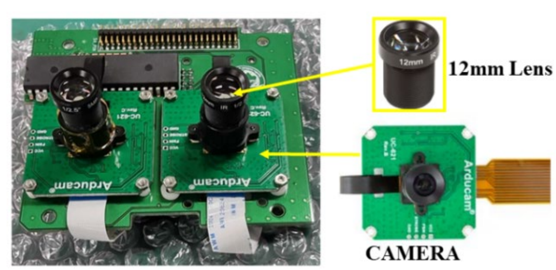

Figure 5: Mission Board 2 with Camera System Hardware

When the original images are fully downlinked, GIS software is used to perform band combination and analysis of the images to provide an analysis of water quality, soil fertility, and land use and cover. Figure 6 highlights the interpretation of land use and cover at Kyutech's main campus. The images were captured when the payload was carried on the drone.

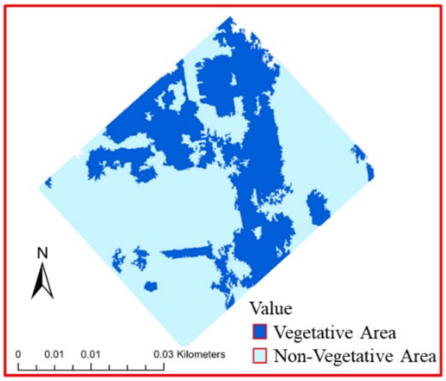

Figure 6: Vegetation Type and Condition at Kyutech

Automatic Packet Reporting System (APRS)

In an Automatic Packet Reporting System (APRS) mission, the satellite receives APRS messages from the amateur community and digipeats them back to the ground. The mission's goal is to serve the amateur radio community and to show the effectiveness of APRS digipeating utilizing low-cost commercial off-the-shelf (COTS) components. The payload consists of a Terminal Node Controller (TNC) linked to a radio transceiver (Radiometrix) tuned to the 145.825 MHz amateur radio band. Both are COTS components from Byonics and Radiometrix. The mission uses a VHF dipole antenna. The antenna design employs a strip line to connect its elements to its feedline. End-to-end ground testing revealed that the payload radio sensitivity is -96 dBm and this allows for space communication. Figure 7 depicts APRS-DP Block Diagrams.

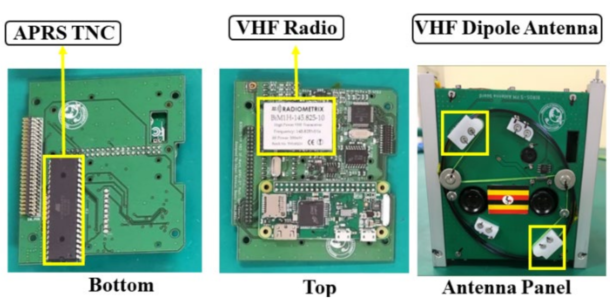

Figure 7: Mission Board 2 with APRS-Module, Transceiver, and the VHF dipole antenna.

Store-and-Forward (S-FW) mission

This mission´s purpose is to demonstrate a data/message store-and-forward (S&F) system in line with the Universal Amateur Radio Text and E-mail messaging. This mission aims to investigate technical challenges through experiments on appropriate data format, multiple access scheme, file-handling protocol while complying with limited operational time and power constraints using the APRS protocol. To do this, it uses the same transceiver as the APRS mission.

Attitude Determination and Control (ADCS) Mission

To capture images of the exact location from space, the satellite must be stabilized to point the exact target before pressing the shutter to capture the images. ADCS mission´s purpose is the demonstration of a passive attitude control and stabilization. ARM STM32F446RE is used as the microcontroller (MCU), the ADCS includes a L3GD20 Gyroscope, MMC5883MA magnetometer. Mission Board 1 with ADCS components is shown in Figure 9.

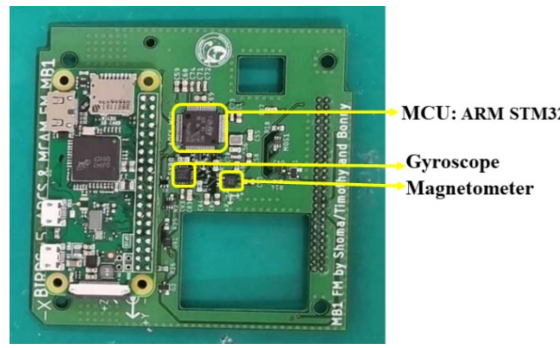

Figure 8: Mission Board 1 with ADCS components

ADCS MCU collects data from magnetometer, and gyroscope chip. The magnetometer communicates with the ADCS MCU using I2C protocol, while gyroscope communicates using SPI interface. ADCS MCU sends the data collected from the sensors to Main PIC via UART. For the passive stabilization, permanent magnets and hysteresis dampers are used. Permanent magnets are attached along the Z-axis of the satellite and hysteresis dampers are on the -Z panel. Permanent magnets change the satellite's attitude to follow the geomagnetic field, and hysteresis dampers serve to eliminate oscillations.

Discussions:

Lessons Learnt.

Important lessons learned by the team during the planning and implementation of PearlAfricaSat-1 satellite should be laid down clearly so that other countries and satellite project do not fall in the same trap. These include both technical and non-technical lessons as follows:

Before any country makes a national commitment to participate in the space sector, it should always have answers to the following questions: why go to space? how does space help ordinary citizens? and how does space improve the country's workforce and R&D? Perhaps these could be answered in the National Space Policy and Framework.

Learn by doing. The new space has greatly lowered many obstacles into space for developing counties however, it is still not yet a cakewalk. Get hands on experience rather than buying already-made satellites or satellite imagery.

Don't just build and launch the first satellite. The space industry is no different from other industries. A start-up is still a start-up. Most countries are stuck on a premise like "we are new space entrants," but then they lack insights on how to solve the problems their citizens are facing. Being able to launch the first satellite is cool, but don't just stop there.

Don't start because other countries have started.

Endeavor to carry out extensive consultations with every stakeholder to understand how they solve their problems today and what they need to get solved. The local community will tell you the satellite missions. Space is no longer a national prestige rather must be to solve the problems of the Nationals.

Don't keep the project within the key stakeholders (Engineers, Lab and perhaps funders) walls but share it with the local community, and authorities in order to provide an added social value.

Frequency coordination. This is a technical and regulatory process that requires cooperation with multiple entities in order to operate on a specific frequency. Because this process takes time, documentation should be processed as soon as possible in order to obtain a frequency license. Delays in obtaining a frequency license can cause satellite launches to be delayed.

Calculation of the power budget. At the absolute least, a balance between power use and power generation must be reached. During nominal and mission execution conditions, all subsystems and payload power consumptions must be considered. Also, ensure that the power supplied by the solar panels has enough margin to charge the battery and provide power to the load even if some of the solar panels fail.

Long duration test. This test is an emulation of how the satellite should operate in orbit. Therefore, the entire test should not only focus on the individual mission execution, but more importantly the system performance as a whole. In cases where software related issues in subsystem level, mission level or system level are encountered, these should be addressed and fixed. Schedule another long duration tests each time an issue is identified and solved, until a smooth operation is realized.

Flight software. "Do not modify once something has worked unless there is a compelling reason to do so," we say. When the long duration test results fulfill the requirements, the flight software is declared final. No more changes should be made because they may interfere with satellite operation.

Test as you fly. When conducting functional tests and space environmental tests, endeavor to set all parameters to suit the actual in-orbit operations. This allows easy identification of anomalies that might exist in the system. For the satellite, once deployed, it can not be retracted for repair. Therefore, perform as many tests as possible mimicking in-orbit operations.

Significance of this satellite for Uganda

Uganda has joined the eleven (11) African countries to have an existence in space exploration. Until recently it did not have the minimum capacities, infrastructures, and necessary conditions to aspire to contribute to economic, scientific, and social development through a sustainable space program. Therefore, the development of PearlAfricaSat-1 has the following potential spinoff effects.

The first satellite for Uganda is a source of national pride, just as it would be for any country, but the big difference here is that the first satellite was designed to help ordinary citizens, improve the industrial base, and increase R&D capabilities in Uganda. The camera and store and forward missions are very significant in transforming the agricultural sector and managing disaster-related issues in the country.

Uganda built its first satellite by using its own engineers. This means that the country has raised a generation of competent space engineers who will foster space science and technology in the country, build the capacity of other young engineers and build subsequent satellites in-house.

Having the first satellite for Ugandans does not only imply acquiring knowledge and skills in satellite design, development, and operation but also the acquisition of long-term space infrastructure such as the ground station and ground sensor terminals, which are necessary for future satellite projects as well as space education and outreach activities. This infrastructure will greatly reduce the cost of subsequent satellite projects in the country.

The country's first satellite is indeed a turning point in Uganda's and the world's technological and scientific growth. Because of the first satellite, millions and millions of writers, bloggers, and tweeters helped put Uganda on the map. The impact was felt at all levels of the country, inspiring, encouraging, and serving as a signal of hope for Ugandans to imagine a better future.

Conclusion

PearlAfricaSat-1 was developed together with 1U CubeSat for Zimbabwe and a 2U for Japan under BIRDS-5 project. The CubeSats will be launched and deployed in orbit from the International Space Station in October and November, respectively. This paper presented the summary about each subsystem and mission design and how the missions are tailored to solve the problems of the ordinary Ugandans. The multispectral camera and store and forward mission are very significant in transforming the agricultural sector, and disaster management in the country.

To improve the reliability of future projects and encourage more space entrants, both technical and non-technical lessons learned were discussed showing the importance of carrying out exhaustive tests for different operating scenarios in order to mitigate possible failures. Lastly, this paper talked about the impact of the first satellite.

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References:

[1] T. Ward, K. City, T. Ward, and K. City, "Dr. Maxwell Otim," no. October, pp. 25–29, 2021.

[2] National Planning Authority, "Uganda Vision 2040," *Annu. Meet. Midwest Polit. Sci. …*, vol. 12, no. 3, pp. 88–89, 2007, [Online].

[3] "Ugandan space initiatives - Wikipedia." https://en.wikipedia.org/wiki/Ugandan_space_initiatives (accessed Oct. 02, 2022).

[4] S. Kim, G. Maeda, and M. Cho, "BIRDS Program Digital Textbook," pp. 1–74, 2019.