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ORIGINAL RESEARCH ARTICLE

CRANFIELD UNIVERSITY AND UNIVERSITY OF MAIDUGURI CUBESAT (CUUMCUBE) FOR TECHNOLOGY DEMONSTRATION: BASELINE AND MISSION DESIGN

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ABSTRACT

CubeSats are small satellites that can be deployed to orbit to achieve various space mission goals. Lately, there are several CubeSat launch opportunities from the International Space Station (ISS). For University of Maiduguri to be able to bid for such launch opportunities there is a need for a baseline for a spacecraft and a mission design. Thus, this paper using the Systems Engineering approach is a baseline and mission design for a CubeSat using CubeSat COTS (commercial off-the-shelf) components targeting the KiboCUBE opportunity. CUUMcube mission is a technology demonstration mission to fly two payloads, Cranfield's Acoustic Sensor and De-Orbit Mechanism (DOM). The Acoustic Sensor is a microphone that measures vibrations, it is intended to measure vibrations due to: spacecraft thermal cycling mechanical noise, antenna deployment, Micrometeoroids and Orbital Debris (MMOD) impacts, DOM deployment and changes in acoustic response of spacecraft after deployment of both mechanisms. The DOM is a deployable drag sail, a passive method of removing spacecraft from orbit afterlife in the effort of mitigating space debris.

Thus, mission baseline reached after the design is to deploy a 1U CubeSat, to carry two payloads (Cranfield's Acoustic Sensor and DOM), using COTS components. The deployment of the spacecraft will be from the ISS into an elliptical orbit (perigee: 380km, apogee: 420 km).

The ground control stations are COTS component too, where there will be one each in UK and Nigeria. Lastly, 30 mins after deployment into orbit the mission sequence starts from the activation of spacecraft to 24 hours recording mode to monitoring mode by the acoustic sensor to capturing of vibrations. Hence, the antenna and the DOM will be deployed. The DOM will speed the orbit decay of the spacecraft, as a result it will speed the re-entry phase and burn in the process.

1.0 Introduction

CubeSats started as tools for students in academic institutions to access space or as a technology demonstration at a lower cost within two or three years of design and fabrication. However, in recent years CubeSats have grown from mere educational or technology demonstration tools to low-cost real mission (Selva, and Krejci, 2012), the focus of CubeSat applications has been on the following: Technology demonstration, Astrophysics, Astrobiology, Earth remote sensing, Radiation effect on space technologies, Ionospheric and auroral research (Wertz, Everett and Puschell, 2015).

1.1 Technology Demonstration:

The exploitation of CubeSat in technology development started since the inception of the idea. The use of the CubeSat platform for technology demonstration is grouped into two categories; demonstration of technologies planned for larger and more expensive missions and technologies for future CubeSat missions (Poghosyan & Golkar, 2017). An example of a technology demonstration mission for a larger satellite mission is NASA's GRIFEX (GEO-CAPE ROIC In-Flight Performance Experiment), a 3U CubeSat which assesses digital in-pixel high frame rate Read-Out Integrated Circuit (ROIC) (NASA, 2015a). GRIFEX is designed to validate detector technology for the Panchromatic Fourier Transform Spectrometer (PanFTS) which is an imaging FTS for Geostationary orbit (NASA, 2015b).

1.2 Astrophysics:

Astrophysics missions are intended at understanding the universe and our place in it, it is concerned with answering the very basic questions about the evolution of the universe and investigate the history of stars and galaxies by observing them with sophisticated payloads (NASA, 2015b). CXBN (Cosmic X-ray Background Nanosatellite) and CXBN-2 missions are examples of astrophysics missions; CXBN is a 2U CubeSat launched in 2012, its objective is to improve cosmic X-Ray background precision measurements in the range of 30-50 KeV using Cadmium Zinc Telluride (CZT) detector to have a better understanding of the origin and evolution of the universe (Healea, et al., 2015). Based on the results of CXBN, CXBN-2 was launched in 2016 as an improvement for better results (Ishimaru, et al., 2014). S-CUBE is another example, it is a 3U CubeSat which was aimed at the observation of meteors from LEO to study their size and compositions using a camera to take visible images and three photomultiplier tubes (PMT) to observe UV emissions (Ishimaru, et al., 2014).

1.3 Astrobiology

Humans have contemplated the existence of life somewhere else beyond earth for years (NASA, 2008). Scientists have been studying how living organisms adapt to the space environment and what are its effects on them (NASA, 2008). Some of the questions scientists are trying to find answers to are: what are the effects of living on Mars for years, how do living organisms behave in space weather, astrobiology is concerned about answering such questions. In a nutshell, Astrobiology studies the origin, evolution, distribution and future of life in the universe (NASA, 2008). Thus, O/OREOS (Organism/Organic Exposure to Orbital Stresses) is an astrobiology CubeSat mission which carried out two distinct experiments: Space Environment Survivability of Live Organisms (SESLO) experiment which carried two populations of the microbe Bacillus subtilis into orbit and observed the effect of the space environment on them, and the second experiment is Space Environment Viability of Organics (SEVO), which monitored the stability and changes in four classes of organic molecules (Ehrenfreund et al., 2014).

1.4 Earth Remote Sensing

Earth observation (EO) has great scientific and economic incentives such as natural resource exploitation, study climate change, weather, natural disasters, and emergency and security management, which is worth billions of dollars for countries economy around the globe (NASA, 2015b). The thermosphere is a key region for atmospheric changes which we have limited knowledge about. In low earth orbit (LEO) big satellites undergo a large amount of atmospheric drag making them lose altitude after 6-12 month and then burn up during re-entry, spending ₦82 - ₦123 billion to put a satellite in LEO is not worth it (CUBESATS, 2017). This makes CubeSats a suitable alternative due to their low cost, they can be used for suicide missions to LEO to carry out the intended mission objectives within 1-4 years and then burn up during re-entry (CUBESATS, 2017). One of the future CubeSat missions to LEO is the QB50 mission, it is a constellation of 50 CubeSats (some already launched) built by universities all over the world to study the lower thermosphere (200-380 km altitude). The payloads QB50 CubeSats carry are different type of science sensors, e.g., Ion-Neutral Mass Spectrometer

(INMS), Thermistors/thermocouples/RTD (TH), Flux-Φ-Probe Experiment (FIPEX). (QB50, 2017).

1.5 Radiation Effect on Space Technologies

Radiation has detrimental effects on spacecraft and health implication for human in space, making it vital to study and understand the nature of space weather (Poghosyan and Golkar, 2017). Radio Aurora Explorer (RAX) mission consisting of two 3U CubeSats RAX-1 and RAX-2 built by University of Michigan in collaboration with Stanford Research Institute (SRI) International, the primary mission objective is to examine the formation and distribution of natural ionospheric plasma turbulence, using ground-to-space bistatic radar experiment (Springmann and Cutler, 2014).

1.6 Review of CubeSat COTS Components

COTS components made the design of CubeSat cheap and possible for institutions and countries with limited manufacturing technology, these components are readily available in the market for everyone to purchase. There are lots of companies that venture into CubeSat, they provide services ranging from launch, research and development, and components. Some of the leading companies which provide CubeSat components are Clyde Space, EnduroSat, ISIS-Innovative Solutions in Space, Tyvak Nanosatellite Systems Inc., GomSpace, Spaceflight, Pumpkin Inc., Crystalspace, CubeSatShop, Nano Avionics. A CubeSat consists of several subsystems which are integrated to form a single system of a CubeSat. CubeSat subsystems available in the market include Payload, Structure, Power systems, Communication systems, Attitude Determination and Control systems, On-Board Data Handling systems, Ground Station, Propulsion system and Integrated CubeSat platforms. Going through the companies (mentioned earlier) it is obvious that CubeSat COTS components are all similar (in their specifications), this is because of the standardization of CubeSat components dictated by launchers, communication regulations and technology advancement.

1.7 Review of KiboCUBE Opportunity

The KiboCUBE opportunity is a collaboration programme between the Japanese space agency (JAXA) and the United Nations Office for Outer Space Affairs (UNOOSA) for the deployment of CubeSats to orbit from the international space station (ISS) via Japanese Experimental Module JEM "Kibo" (UNOOSA, 2017). KiboCUBE programme was initiated in line with the aims and objectives of the UN Programme on space applications. Moreover, UNOOSA and JAXA believe that the KiboCUBE programme will aid developing countries in the following ways (UNOOSA, 2017):

1. contribute to the growth of spacecraft engineering, design and manufacturing at a national scale and limit space activities (in terms of launch)

2. raise awareness towards the role space science and technology can play in promoting sustainable development (MEXT, 2015)

1.8 The Japanese Experimental Module (JEM) "Kibo"

The Japanese Experiment Module (JEM) alternatively called Kibo is JAXA's first contribution to the ISS. It is built to be used for the conduction of scientific research on orbit, with a maximum number of four astronauts capable of performing experiments (scientific, medical and educational experiments) at a time. The Kibo consists of six major segments (Figure 1 shows these segments) the segments namely are (JAXA 2007a):

I. Pressurized Module (PM)
II. Exposed Facility (EF)

III. Experiment Logistics Module-Pressurized Section (ELM-PS)
IV. Experiment Logistics Module-Exposed Section (ELM-ES)
V. Japanese Experiment Module Remote Manipulator System (JEMRMS)
VI. Inter-Orbit Communication System (ICS)

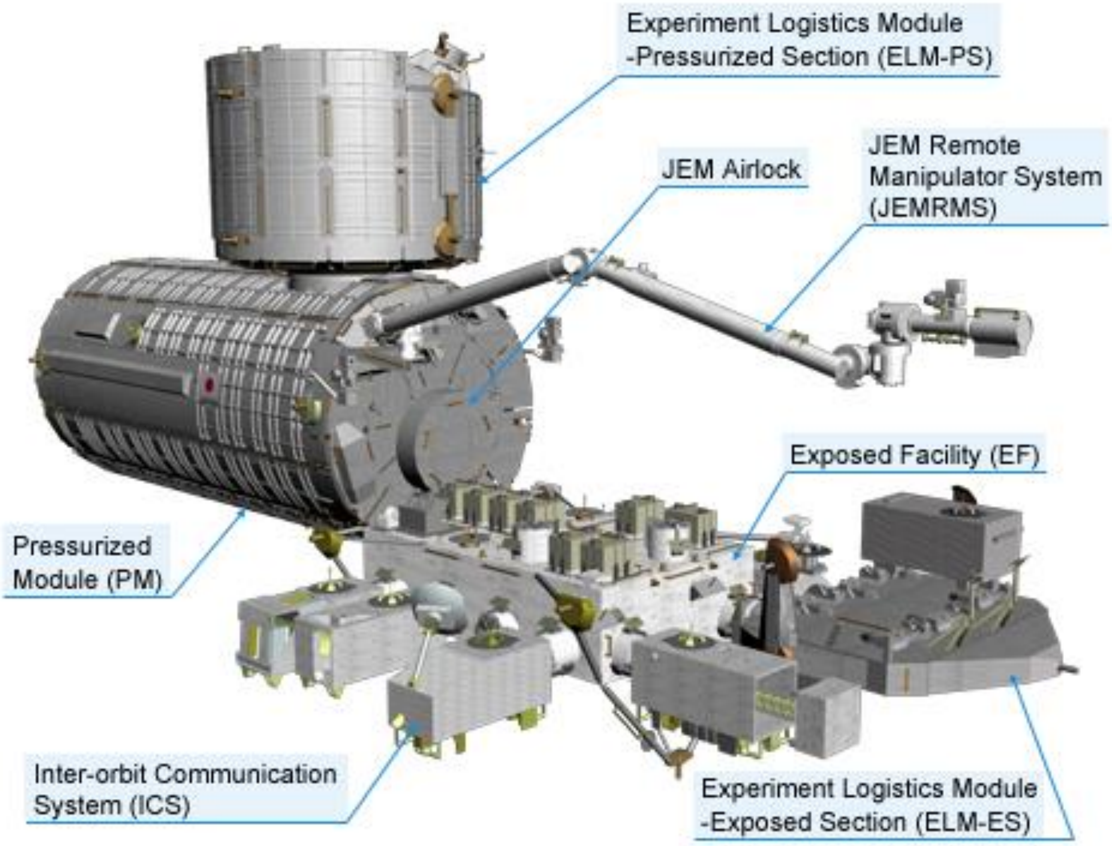

Figure 1 Kibo Configuration Showing Its Segments (JAXA, 2007b)

2.0 CUUMcube MISSION PAYLOADS

2.1 Payload 1: Acoustic Sensor

CUUMcube mission consists of two payloads, both payloads are aimed at demonstration of technology. Cranfield's Acoustic Sensor identical to Knowles I2S Output Digital MEMS - Microelectromechanical Systems Microphone in its function and specifications (Figure 2). It is a microphone that will be measuring the spacecraft vibrations resulting from spacecraft thermal cycling mechanical noise, antenna deployment, MMOD impacts, DOM deployment and changes in acoustic response of spacecraft after deployment of both mechanisms – in the current case CUUMcube spacecraft.

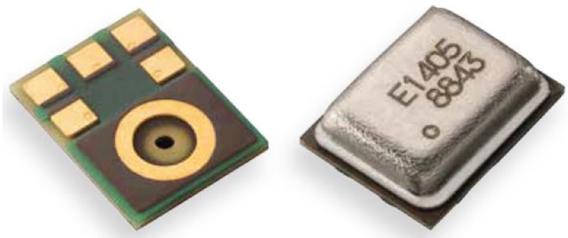

Figure 2 Knowles I2S Output Digital MEMS Microphone (Knowles, 2017)

Knowles I2S Output Digital MEMS Microphone is a low power Micro Electro Mechanical System that can be directly connected to a digital processor, application processor or microcontroller, with an interface to condition the signal into 24 bits I2S format (Knowles, 2017). It detects vibrations (noise or sound) within the range of 50 Hz – 15 kHz and converts it to a voltage with a digital output. Within a spaceflight context, this is expected to monitor spacecraft vibrations and shocks transmitted through the spacecraft structure and into the microphone package mechanically coupled to the spacecraft structure.

Table 1: of Specifications of the Acoustic Sensor

Mass	4 g
Dimensions	(3.50 x 2.65 x 0.98) mm
Power	1.6 - 3.6 V
Input Current	100 mA
Interface Compatibility	(Works with microprocessors and microcontrollers) like Cortex M-series chips like single-board computers (such as raspberry pi), Feather M0 and Arduino Zero with I2C, SPI or RS-232 busses
Operating Temperature	-40 to +100 °C
Data Rate (size)	7400 bps (24-bit I2S format)
Vibration Test	16 mins in all axes (X, Y and Z) from 20 – 2000 Hz and can withstand an acceleration of up to 20 G
Mounting	mechanically mounted internally on CubeSat structure
Ionizing Radiation Tolerance	10 krad

2.2 Payload 2: Cranfield DOM (De-Orbit Mechanism)

The DOM (De-Orbit Mechanism) is a mechanism for removing spacecraft from orbit (de-orbit) after completing its mission. It is a passive method of removing debris from orbit. Thus, the initial design of the DOM has a size of 140 mm x 80 mm x 56 mm with an area of up to 0.01 m^2 and a mass of 0.5 kg. However, the currently available DOM design has a mass of about 38% of the total mass of a 1U CubeSat, the design was reduced to perfectly fit in a 1U CubeSat. The DOM uses the concept of stored energy: using copper-beryllium tape spring booms attached to a freely rotating central spool at one of its ends (Taylor, 2013). Figure 3 shows the configuration of the DOM and Table 2 shows its specifications.

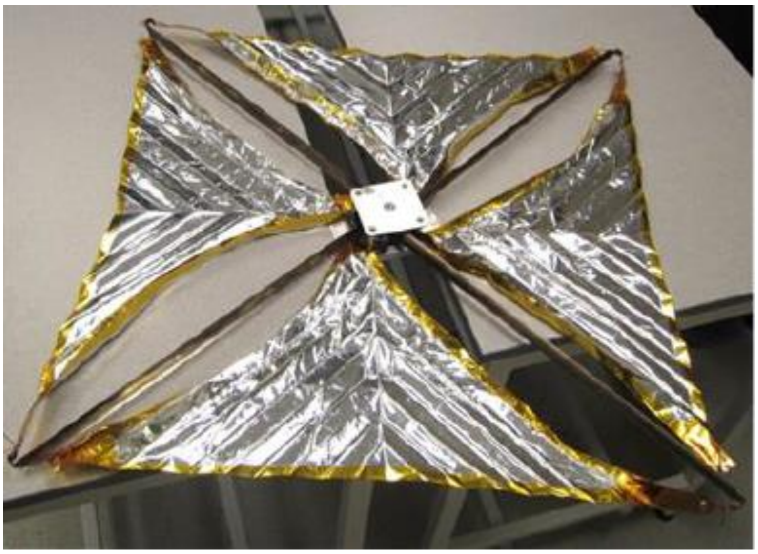

Figure 3 Deployed Cranfield DOM (Taylor, 2013)

Table 2 Specifications of the DOM

Dimension	(100 x 80 x 16) mm
Area	0.008 m^2
Mass	400 g
Power Requirement	200 mA for 10 milliseconds
Mounting	screwed to the CUUMcube structure via four bolts
Operating temperature	- 40 to +100 °C
Ionizing Radiation	the materials are tolerant to ionizing radiation

3.0 Materials and Methods

3.1 CUUMcube Mission Design Key Drivers

The Mission key drivers are the critical aspects and requirements which must be considered as a priority to successfully design a mission. CUUMcube mission key drivers are identified as:

I. payload
II. mass
III. communications
IV. power

This is because the mission is a technology demonstration mission, the aim is for the payload to work effectively and efficiently, alongside making sure everything fits in a 1U CubeSat structure with a standard mass of ≤1.33 kg, anything more than that will be rejected by KiboCUBE programme. As a result, in the process of CUUMcube mission design, special attention is given to the payload and mass (requirements). Besides, the electrical power subsystem is also a key driver, due to the (power) demands and requirements imposed on it by the two mission payloads, the communications, the ADCS and the OBDH subsystems, all these subsystems require a power source (power supply), therefore, making it a challenge to provide enough electrical power supply. Besides, communications subsystems usually occupy one-third of the mass of a spacecraft, thus, making it very thought-provoking to design a mission with an efficient communications subsystem.

3.2 Subsystems Design Alternatives

Taking CUUMcube requirements and constraints into consideration, subsystems were sized. The design methodology employed is the performance of trade-off analysis amongst available COTS components in the market, however, the trade-off was performed after sizing CUUMcube various subsystems. These components are provided by several companies, giving a wide range of components to choose from, despite the fact they are standardized, however, certain parameters were taken into consideration for trade-off analysis, to optimize the design. The parameters employed to make the trade-off analysis were:

- **Compatibility:** the component must be compatible with the payloads and mission demands in terms of requirements such as interface and mass.
- **Simplicity:** the component must be simple to integrate into the entire design.
- **Performance:** the component must be able to provide the desired demand of service to the entire mission and payloads.

Alongside these parameters, careful consideration for mass and power consumption was paid attention to, this is because the mission is constrained by mass, hence limiting the amount of power produced.

3.3 CUUMcube Orbit

The orbital parameter analysis of CUUMcube was done using Systems Tool Kit (STK) software, to find the ground track pass and access time of CUUMcube concerning the ground station, the following parameters were used for the analysis:

- Perigee Altitude: r_p = 380 km
- Apogee Altitude: r_a = 420 km
- Inclination: i = 51.6°
- Access Time:
    - Start: 7th April 2021, Stop: 30th April 2021
- Target Areas: Cranfield, Bedford, UK and Maiduguri, Borno, Nigeria

CUUMcube mission is constrained by the orbit and inclination of the ISS (given the lack of a propulsion subsystem) after running STK simulation of the orbit the results showed that CUUMcube will be able to access both the UK and Nigeria (good for the ground station to communicate with CUUMcube and vice versa), Figure 4 shows the ground track of CUUMcube.

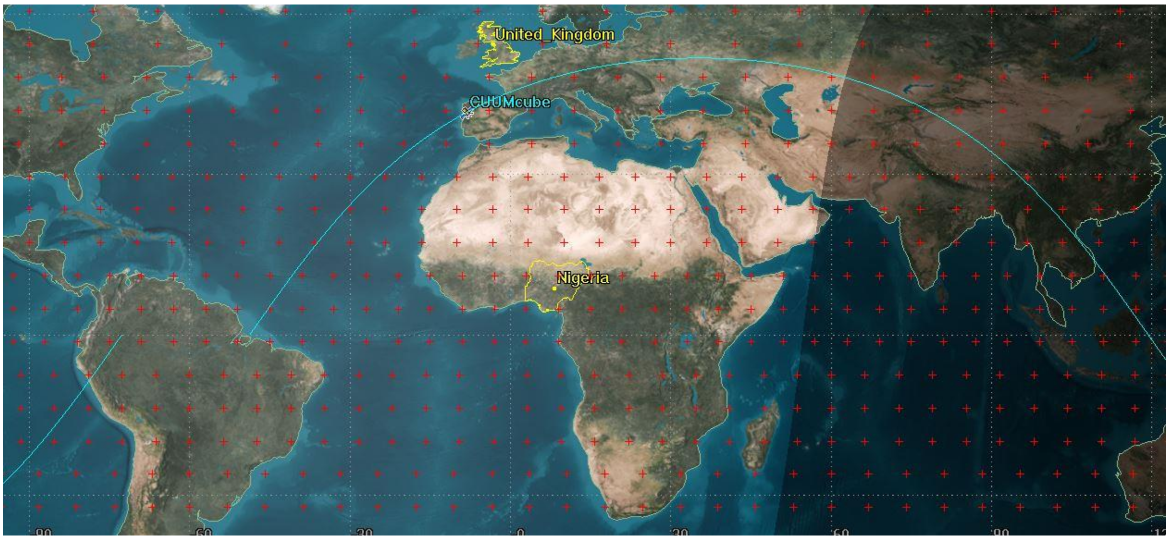

Figure 4 the ground track pass of CUUMcube over UK and Nigeria (STK)

3.4 Communication Time (Maximum Time in View)

The maximum time in view (access time) is the time duration where CUUMcube can see and communicate with the ground station. The average maximum time in view (or access time) at 380 km (CUUMcube orbit apogee) is 5.98 minutes and 6.52 minutes at 420 km (CUUMcube orbit perigee), these values are at 10° angle of elevation (to account for obstacles such as tall buildings) (Wertz et al., 2015).

However, the exact access time was obtained from STK simulations (Table 3 and Table 4), the simulation was done for the date: 7th April 2021 to 30th April 2021 (expected active CUUMcube mission lifetime). The red marks on Figure 4 show the coverage on the ground. Results from Tables 3 and 4 show that each day CUUMcube have access to both UK and Nigeria (ground stations) five to seven times per day (in every 48-hours there are 13 orbits), with an average access time of about 10 minutes per orbit. Therefore, the total access time per day is 3612 seconds, (60 minutes).

Table 3: Access Summary Report of CUUMcube Over UK

```
Page 1

 7 Apr 2021 07:09:44
Civil Air Patrol Use Only
Satellite-CUUMcube-To-Place-Bedford:  Access Summary Report


CUUMcube-To-Bedford
-------------------
                  Access       Start Time (UTCG)          Stop Time (UTCG)
      Duration (sec)
                  ------    ------------------------    ----------------------
--    --------------
                       1     7 Apr 2021 12:44:36.020     7 Apr 2021 12:53:07.3
53             511.334
                       2     7 Apr 2021 14:20:24.189     7 Apr 2021 14:31:48.3
68             684.178
                       3     7 Apr 2021 15:58:01.159     7 Apr 2021 16:09:54.9
34             713.776
                       4     7 Apr 2021 17:36:07.687     7 Apr 2021 17:48:01.3
83             713.696
                       5     7 Apr 2021 19:14:14.309     7 Apr 2021 19:25:37.5
55             683.245
                       6     7 Apr 2021 20:52:56.543     7 Apr 2021 21:01:23.3
50             506.807
                       7     8 Apr 2021 12:16:35.901     8 Apr 2021 12:24:47.3
84             491.483
                       8     8 Apr 2021 13:52:13.742     8 Apr 2021 14:03:33.8
24             680.082
                       9     8 Apr 2021 15:29:47.245     8 Apr 2021 15:41:40.6
61             713.416
                      10     8 Apr 2021 17:07:53.395     8 Apr 2021 17:19:47.4
12             714.017
                      11     8 Apr 2021 18:45:59.827     8 Apr 2021 18:57:26.8
68             687.042
                      12     8 Apr 2021 20:24:37.150     8 Apr 2021 20:33:22.4
37             525.287
                      13     9 Apr 2021 11:48:36.955     9 Apr 2021 11:56:26.5
50             469.595
```

Table 4: Access Summary Report of CUUMcube Over Nigeria

```
 7 Apr 2021 07:11:47
Civil Air Patrol Use Only
Place-Maiduguri-To-Satellite-CUUMcube:  Access Summary Report


Maiduguri-To-CUUMcube
---------------------
                  Access        Start Time (UTCG)            Stop Time (UTCG)
      Duration (sec)
                  ------    ------------------------    ----------------------
--    --------------
                     1     7 Apr 2021 11:00:00.000     7 Apr 2021 11:10:38.3
55            638.355
                     2     7 Apr 2021 19:26:25.659     7 Apr 2021 19:31:54.4
26            328.767
                     3     7 Apr 2021 21:01:42.836     7 Apr 2021 21:13:26.9
77            704.142
                     4     7 Apr 2021 22:41:59.446     7 Apr 2021 22:48:48.9
74            409.528
                     5     8 Apr 2021 08:54:44.940     8 Apr 2021 09:02:49.9
23            484.983
                     6     8 Apr 2021 10:30:48.750     8 Apr 2021 10:42:27.0
38            698.288
                     7     8 Apr 2021 12:13:32.327     8 Apr 2021 12:16:45.9
24            193.597
                     8     8 Apr 2021 18:58:42.235     8 Apr 2021 19:03:02.9
18            260.683
                     9     8 Apr 2021 20:33:30.386     8 Apr 2021 20:45:11.7
06            701.321
                    10     8 Apr 2021 22:13:23.070     8 Apr 2021 22:20:58.8
58            455.787
                    11     9 Apr 2021 08:26:52.148     9 Apr 2021 08:34:16.2
87            444.139
                    12     9 Apr 2021 10:02:32.838     9 Apr 2021 10:14:15.0
67            702.229
                    13     9 Apr 2021 11:44:30.966     9 Apr 2021 11:49:11.9
04            280.938
                    14     9 Apr 2021 18:31:14.131     9 Apr 2021 18:33:55.4
73            161.343
                    15     9 Apr 2021 20:05:18.592     9 Apr 2021 20:16:55.5
54            696.962
```

3.5 Data Rate Required for CUUMcube Mission

The Acoustic sensor with a data rate of 7400 bps (bits per second), will be recording for 24 hours (only once to get a control data sample upon which, subsequent recordings will be compared). The TT&C data (Telemetry and Tracking: orbit position, OS operating system and fault detection) is less than 250 kB per day, it is negligible compared to that of payload (Acoustic sensor). Table 5 shows the data sizing the mission.

Table 5 The Total Amount of Data That Needs to Be Sent to The Ground Station

Payload Data	7400 bps for 24 hours (86400 seconds) = 639.36 Mb per day
TT&C Data (telemetry, tracking, and housekeeping data per day)	250 kB/day = 2 Mb/day
Total Data Need to Be Sent to the Ground Station	639.36 Mb + 2 Mb = 641.36 Mb/day
Total Spacecraft Access Time Per Day (max. time10)	4411 s (74 minutes)
Required Mission Download Data Rate per Day	(641.36 Mb) / (4411 s) =145.4 kbps

Therefore, a downlink download data rate with at least 145.4 kbps is required to send mission data to the ground station (daily). Similarly, for uplink; telecommand data from the ground station (to command spacecraft) is less than 800 kb/day (an estimation of a couple of codes with 0's and 1's), therefore a data rate of (800 kb/4411 s) 181 bps (per day) is required to send telecommand data to spacecraft from the ground station. Therefore, a downlink download data rate with at least 145.4 kbps is required for sending mission data to the ground stations (daily).

4.0 Results

CUUMcube mission design was done using the Systems Engineering approach, where the mission requirements were put together against which this baseline emerged after careful trade-off analysis. Moreover, the mission design was done using COTS components because these components are relatively affordable, reduce fabrication time (they are available off the shelf ready to be assembled) and have flight heritage (Technology readiness levels) TRL 5-9, hence mitigating the risk of mission failure. Consequently, the following points describe the CUUMcube mission baseline drawn from the Systems Engineering design approach. Therefore, CUUMcube should (baseline):

I. Fabricated using COTS components
II. Use a 1U CubeSat structure
III. Fly two payloads (to demonstrate technology), which are:
    a. Cranfield's Acoustic Senor and
    b. the DOM (de-orbit mechanism)

Deployed to an elliptical orbit (perigee 380 km, apogee: 420 km) by Japanese Experiment Module Remote Manipulator System (JEMRMS) via JEM Small Satellite Orbital Deployer (J-SSOD), from the ISS. Summary of COTS component employed in CUUMcube mission are shown on

Table 3 and mission specifics on Table 6

Table 6: Selected COTS components for CUUMcube mission

Subsystem	COTS Component / Manufacturer	Unit
Structure	1U CubeSat structure (ISIS)	1
ADCS	NSS CubeSat ADCS Board (New Space Systems)	1
Communications	UHF NanoCom AX100 Transceiver (GOMspace)	1
	UHF NanoCom ANT430 Antenna (GOMspace)	1
OBDH	OBDH Subsystem (Clyde space)	1
EPS	Electrical Power Subsystem (GOMspace)	1

Table 7: CUUMcube Mission Baseline Key Specifics

Payload	2 payloads: Cranfield's Acoustics Senor and DOM
Orbit	Elliptical orbit (perigee 380 km, apogee: 420 km) with an average 10 minutes access time 6 times per day over UK and Maiduguri (average access time of 57 minutes/day)
Deployment	from the ISS via J-SSOD (JEM)
Launch Mass	1.33 kg,1U CubeSat structure (with 4.8% margin)
Spacecraft Dimension	(100 x 100 x 113.5) mm
Power	60.36 cm^2 provides 15 W (efficiency, η=30.20%)
Battery Capacity	2600 mAh (35% depth of discharge)
Downlink Capability Mission Lifetime Mission Operations	115.2 kbps in UHF About 160 days ground stations in UK (Cranfield University) and Nigeria

	(University of Maiduguri)

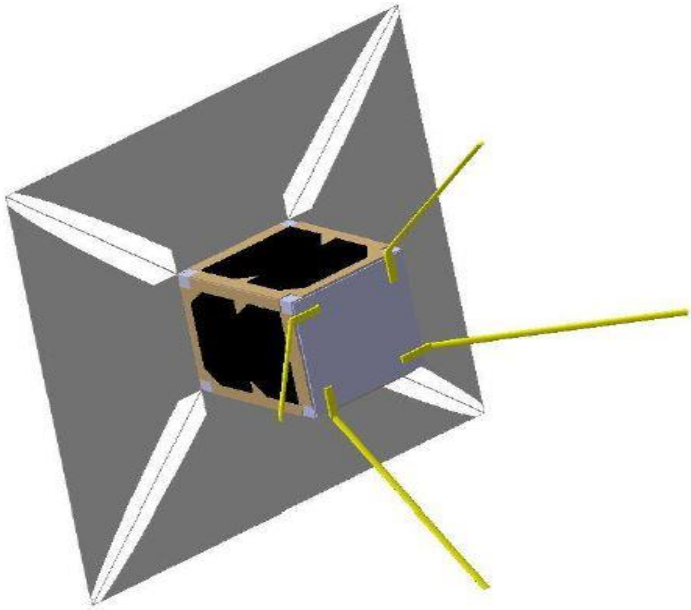

Figure 5 A Catia Model of CUUMcube Spacecraft

4.0 Discussion

4.1 Communications

CUUMcube communications subsystem is designed to have a half-duplex communications link in the UHF (ultra-high frequency) range. This link will be used in sending both mission and telemetry data to the ground stations, and telecommand data onboard the spacecraft from the ground station. Payload 1 (Cranfield's Acoustic Sensor) has a data rate of 7400 bps; it is planned to record continuously for the first 24-hours on-orbit to have control data upon which subsequent data will be compared. Therefore, it generates 641.36 Mb (within 24-hours including 2 Mb TT&C data), hence with 56.7 minutes/day access time, a data rate of 188 kbps is required to download this data. However, the UHF transceiver is having a max. of 115.2 kbps, therefore the data will be stored onboard and subsequently downloaded within 93 minutes. However, after the first 24-hour of recording the payload (Acoustic Sensor) enters monitoring mode, where it only records when there is an event, it has been estimated to record for 60 minutes per day, producing 30 Mb/day, which require only 8.8 kbps to download it within the available 57 minutes of mission access time (per day).

4.2 Mission Operations

The interface used to communicate with the CUUMcube spacecraft is the GOMspace COTS UHF ground station kit, it consists of a module of receiver and transmitter, a computer (PC) and an antenna (3 yogi antennas) tower including a rotor module for steering to track spacecraft RF (Radiofrequency). The mission operational sequence is the determiner of mission duration, however, at the mission altitude CUUMcube is expected to last 160 days (depending on the rate at which the DOM aerobraking induces to the spacecraft by drag), the mission plan is focused on the following key events:

I. 24 hours recording by the payload (once)
II. Monitoring of:

- Antenna deployment
- mechanical noise induced by thermal cycling
- MMOD impacts
- DOM deployment
- Spacecraft response after deployment of mechanisms

Furthermore, after the deployment of the spacecraft to orbit a series of events will unfold sequentially. These events are as a result of a careful design and a successful deployment in to orbit of the spacecraft. These series of events are the mission operational sequences, which are as follows:

I. **Deployment:** this the first stage of the mission, where the spacecraft is out into orbit. During this process, the spacecraft is deactivated.
II. **Activation of Spacecraft:** 30 mins after deployment, the spacecraft is scheduled to switch on, the subsystems will be in sleep mode except for EPS (Electrical power system), where its fully charged battery will supply power to various subsystems.
III. **Switching on Payload 1:** the acoustic sensor alongside the OBDHS (onboard data handling system) is switched on immediately after activation of the spacecraft. Hence, the sensor will start recording for 24 hours nonstop. The OBDHS is required switched on because the data recorded is stored on the (memory) storage device on the OBHS board.
IV. **Monitoring mode:** after recording for 24 hours, the payload enters monitoring mode, in this mode, the spacecraft only records when it senses an event, it stays in this mode for the rest of the mission duration.
V. **Deployment of Communications Antenna:** 24 hours of deployment of the spacecraft in to orbit, the onboard communications antenna is deployed, while the acoustic sensor is monitoring and recording the event. This delayed is intended to give the acoustic sensor enough events to record, thereby providing more data to analyse.
VI. **Switching ADCS (attitude dynamics and control system) ON:** the ADCS is activated to stabilize the spacecraft and to make sure the side where the DOM is installed is in the ram direction (direction of drag).
VII. **Deployment of DOM: lastly, at the end-of-life of the spacecraft** the DOM is deployed, and then the spacecraft will lose altitude until it burns at re-entry.

5.0 Conclusion

The mission and baseline design are in the context of the KiboCUBE opportunity. Subsequently, the payloads were identified, their requirements alongside other mission requirements were used in the design of the CUUMcube mission, thus, a baseline was outlined, it is as follows: a 1U spacecraft to flying two payloads (Cranfield's Acoustic Sensor and DOM), using COTS components. The spacecraft is to be deployed from the ISS (international space station) into an elliptical orbit (perigee: 380km, apogee: 420 km). The ground station is a COTS component too (just like the spacecraft), with each in both Universities (Cranfield University and University of Maiduguri). The mission payloads are Cranfield's Acoustic Sensor, a microphone for monitoring vibrations resulting from; deployment of mechanisms (antenna and the DOM), vibrations due to thermal cycling, spacecraft response to the deployment of mechanisms and MMOD impact. The second payload is the (DOM a de-orbit mechanism).

Furth more, the mission operation sequence starts 30 mins after deployment of spacecraft into orbit, the sequences start by activation of the spacecraft and then commencement of a 24-hour recording (recording mode) by the sensor, subsequently, the sensor will be monitoring (monitoring mode) to capture any vibration. Lastly, the antenna is deployed then the DOM, then the spacecraft is left to decay in orbit, lose altitude and burn in re-entry.

Lastly, Certain areas give scope for the advancement of this work, the first obvious aspect that needs to be addressed is the replacement of DOM (payload 2), University of Maiduguri needs to develop a payload to replace the DOM in the future (each University needs to come up with a payload). Consequently, the new payload will have different requirements, therefore a review of the mission design need to be done. The second aspect which needs further study is the testing procedures. The third aspect that needs to be looked at is the risk, a rigorous risk assessment will help in tackling possible failures. Moreover, the financial budgets need to be rigorously looked into, in future work the companies need to be contacted for information about the prices. Finally, in the mission operations, the software architecture aspect needs to be included and simulation of MMOD (to know the time of impact and nature of the particles), so that a better mission plan can be set.

References

CUBESAT. 2017. CubeSat Design Specification. https://www.nasa.gov/sites/default/files/atoms/files/nasa_csli_cubesat_101_508.pdf accessed on 7 April, 2021.

Ehrenfreund, P., Ricco, AJ., Squires, D., Kitts, C., Agasid, E., Bramall, N., Bryson, K., Chittenden, J., Conley, C., Cook, A., Mancinelli, R., Mattioda, A., Nicholson, W., Quinn, R., Santos, O., Tahu, G., Voytek, M., Beasley, C., Bica, L., Diaz-Aguado, M., Fredericks, C., Henschke, M., Landis, D., Luzzi, E., Ly, D., Mai, N., Minelli, G., McIntyre, M., Neumann, M., Parra, M., Piccini, M., Ramsay, R., Ricks, R., Schooley, A., Stackpole, E., Timucin, L., Yost, B. and Young, A. 2014. The O/OREOS mission - Astrobiology in low Earth orbit, Acta Astronautica, 93: 501- 508.

Healea, J., Malphrus, B., Mckneil, S., Brown, K., Kruth, J., Twiggs, B., Dang, K., Cavins, A., and Byleborodov, Y. 2015. The Cosmic X-Ray Background NanoSat-2 (CXBN-2): An Improved Measurement of the Diffuse X-Ray Background', 12th Annual CubeSat Developers Workshop. Luis Obispo, CA.

Ishimaru, R., Sakamoto, Y., Kobayashi, M., Fujita, S., Gonai, T., Senshu, H., Wada, K., YM, Kurosawa, K., Hosokawa, S., Yoshida, K., Sato, M., Takahashi, Y. and Matsui, T. 2014. CubeSat Mission for UV–Visible Observations of Meteors from Space: S-CUBE (S3: Shooting star Sensing Satellite)', 45th Lunar and Planetary Science Conference, The Woodlands, TX. 1846 LPI Contribution No.1777.

GOMspace. 2017. Subsystems. https://gomspace.com/Shop/subsystems/Default.aspx accessed on 7 April, 2021.

JAXA. 2007a. Japanese Experiment Module (KIBO). http://iss.jaxa.jp/en/kibo/ accessed on 7 April, 2021.

JAXA. 2007b. JEM Small Satellite Orbital Deployer (J-SSOD). http://iss.jaxa.jp/en/kiboexp/jssod/ accessed on 7 April, 2021.

Knowles. 2017. SiSonic™ surface mount MEMS. https://www.knowles.com/products/audio-processors accessed on 7 April, 2021.

MEXT. 2015. New Cooperation Programme "KiboCUBE": Invitation to CubeSat Deployment into Orbit from the Japanese Experiment Module "Kibo" of the ISS, 58th session of the Committee on the

Peaceful Uses of Outer Space Vienna, 12 June 2015. http://www.unoosa.org/pdf/pres/copuos2015/copuos2015tech09E.pdf accessed on 7 April, 2021.

NASA. 2008. Astrobiology: Its Origins and Development. https://www.nasa.gov/50th/50th_magazine/astrobiology.html accessed on 7 April, 2021.

NASA. 2015a. Jet Propulsion Laboratory, GEO-CAPE ROIC In-Flight Performance Experiment (GRIFEX). https://www.jpl.nasa.gov/cubesat/missions/grifex.php accessed on 7 April, 2021.

NASA. 2015b. Small Spacecraft Technology State of The Art. https://www.nasa.gov/sites/default/files/atoms/files/small_spacecraft_technology_state_of_the_art_2015_tagged.pdf accessed on 7 April, 2021.

Poghosyan, A. and Golkar, A. 2017. CubeSat evolution: Analysing CubeSat capabilities for conducting science, Progress in Aerospace Sciences, 88: 59-83.

QB50. 2017. Mission Objectives. https://www.qb50.eu/index.php/project-description-obj/mission-objectives.html accessed on 7 April, 2021.

Selva, D. and Krejci, DA. 2012. Survey and Assessment of The Capabilities of CubeSats for Earth observation, Acta Astronaut. 74: 50–68.

Springmann, JC. and Cutler, JW. 2014. Flight Results of a Low-Cost Attitude Determination System. Acta Astronautica, 93: 201-214, 2014.

Taylor, R. 2013. Conceptual Development of a De-Orbiting Payload for Micro-Satellites in LEO. Cranfield University: MSc thesis Report, MSc Astronautics and Space Engineering.

UNOOSA. 2017. The United Nations/Japan Cooperation Programme on CubeSat Deployment from the International Space Station (ISS) Japanese Experiment Module (Kibo) "KiboCUBE". Available at: http://www.unoosa.org/oosa/en/ourwork/psa/hsti/kibocube_2017.html accessed on 7 April, 2021.

Wertz, JR., Everett, DF. and Puschell JJ. 2015. Space Mission Engineering: The New SMAD. Hawthorne: Microcosm