Development of UiTMSAT-1: An Approach to Lean Satellite Concept

著者	Mohamad Rahim S.N., Mustafa S.N.K., Azami M.H., Zaki S.B.M., Enche Ab Rahim S.A., Jusoh M.H., Cho M., BIRDS-2 Members
journal or publication title	ASM Science Journal
volume	12
number	2
page range	62-71
year	2019
URL	http://hdl.handle.net/10228/00008681

Development of UiTMSAT-1: An Approach to Lean Satellite Concept

S.N. Mohamad Rahim[1], S.N.K. Mustafa[1], M.H. Azami[1], S.B.M. Zaki[1,2], S.A. Enche Ab Rahim[1], M.H. Jusoh[1*], M. Cho[2,] and BIRDS-2 Members[2]

[1]*Faculty of Electrical Engineering, Universiti Teknologi MARA (UiTM), Shah Alam, Selangor, Malaysia*

[2]*Laboratory of Spacecraft Environmental Interaction Engineering (LaSEINE), Kyushu Institute of Technology (Kyutech), Japan*

This paper presents the development of the UiTMSAT-1 nanosatellite and the approach towards a lean satellite concept. The lean satellite concept comes from extensive reports and discussions among many satellite developers and space players with the increased capability and technology in producing small satellites from the introduction of the CubeSat Project. The concept makes aware the importance of low-cost technology and fast delivery system of the satellite as compared with the traditional satellite development process. The UiTMSAT-1, which is the Universiti Teknologi MARA (UiTM)'s first nanosatellite, underwent the lean satellite concept and scheduled development in its BIRDS-2 project. A work breakdown structure was created to have a well-defined description of the divisions involved in the UiTMSAT-1 nanosatellite development. UiTM, as the stakeholder of Malaysia's team in the BIRDS-2 project contributed during the whole process including the installation of the UiTM ground station to track and monitor the nanosatellites. A brief analysis was presented based on the UiTMSAT-1's housekeeping data of approximately three months preliminary observations since its deployment into orbit.

Keywords: UiTMSAT-1; nanosatellite; lean satellite concept

I. INTRODUCTION

CubeSat is a cubic-like structured small satellite. It has a standardized platform of 1U with a limited weight of not more than 1.33kg and 10 cm length for each side. The standard was introduced by the CubeSat Project in 1999 which intended to decrease the satellite development duration and cost, and to increase launch opportunity (Mehrpavar *et al.*, 2014) with standardized satellite buses structures, and subsystems. This project enabled academia and commercial corporations to perform space research and exploration at an affordable cost. It led to many studies and research work on the development of a small satellite. Continuing from the CubeSat introduction, studies were conducted on the design of small satellites for low earth orbit (LEO) store-and-forward (S&F) automatic packet reporting system (APRS) applications (Addaim *et al.*, 2007; 2008a; 2008b). The research concentrated on designing reliable LEO nanosatellites with APRS capability and S&F technology for data collection purposes. The design used low-cost components which made the technology achievable and practical.

Advancing to the year 2009, the Institute of Space Technology (IST) in Pakistan started a student satellite program called ICUBE based on the conceptual development of the CubeSat Project. The program gave students the educational values, skills and first-hand experience in developing satellites (Mahmood *et al.*, 2011). The program's main objective was for students to be involved in the designing, developing, integrating and launching processes of picosatellites. The second objective of the program was related to the communication, in-orbit operation and collection of the satellite's data. As a result of the program, their first satellite, ICUBE-1, was

*Corresponding author's e-mail: huzaimy@salam.uitm.edu.my

developed and launched in 2013. The existence of ICUBE-1 proved that the CubeSat Project was beneficial in creating an educational project within academia.

In addition, in 2017, the INSPIRE-II, with its purpose of technology and thermospheric research, was deployed from the International Space Station. INSPIRE-II was a 2U CubeSat which was part of the satellite constellation of the QB50 project. The CubeSat was developed by a group of undergraduate and postgraduate students from the University of Sydney, Australia (Soh *et al*., 2013). Similarly, an educational project on satellite development also emerged in Canada at the initiative of the Canadian CubeSat Project (Canadian Space Agency 2018). This project offered post-secondary institutions' students the opportunity to participate in a space mission. The project allowed the winning teams the opportunity to design and build their own CubeSat satellites. From the above mentioned examples, it could be concluded that the introduction of the CubeSat Project had inspired many research studies in space exploration and nanosatellite technology.

II. LEAN SATELLITE CONCEPT

The ability and feasibility to produce small satellites had increased for both academia and commercial corporations like Planet Labs (Boshuizen *et al*., 2014) with the introduction of the CubeSat Project. In fact, small satellites like CubeSat had gained popularity due to their lower cost and fast delivery. Due to that, the term "Lean Satellite Concept" was introduced at the International Workshop on Small Scale Satellite Standardization (IWS4) in November 2014 (Cho *et al*., 2015). Usually, the conventional satellite developers emphasized more on the functionality and linearity of the satellites with thorough testing procedures on the design and the requirement to avoid any risk, for example in the ICUBE-1 CubeSat which was developed by using the proven commercial off-the-shelf (COTS) components (Mahmood *et al*., 2011). On the other hand, the lean satellite concept proposed a low-cost, non-traditional risk-taking approach in its design by a smaller number of team members (Cho, & Graziani, 2017). Furthermore, the delivery time of the satellite based on this concept was shorter than that of the conventional satellite, thanks to the simplified procedures which focused on the significance tests as per the satellite's specifications and requirements.

Furthermore, the development of CubeSat by using the lean approach which utilized non-space-grade COTS components in its design reduced the development cost of the satellite and made the satellite technology more accessible to those who had limited funds/budget. Consequently, the participation from universities in the research and development of CubeSat had increased. Following the new concept, satellite development activity had been structured to fit the lean approach such as in the Horyu-4 project (Masui *et al*., 2015) and the AOBA-VELOX III project (Cho & Fukuda 2017).

The introduction of the lean satellite concept also created many opportunities for undergraduate and graduate students to receive hands-on experience in developing satellites such as in the Joint Global Multi-Nation Birds Satellite (BIRDS) projects. The BIRDS project was hosted at the Kyushu Institute of Technology (Kyutech), Japan. This project provided a platform for students from developing nations to learn about satellite development (Khan *et al*., 2015). Until today, there had been four BIRDS projects conducted by Kyutech, with UiTMSAT-1 being the outcome of the BIRDS-2 project.

III. UiTMSAT-1

In the BIRDS-2 project, three identical IU CubeSats were developed. These CubeSats were built by a group of students from four nations; Japan, Malaysia, the Philippines, and Bhutan. Two UiTM (Malaysia) students with another nine students; three from Japan, two from the Philippines, and four from Bhutan made up the

BIRDS-2 members. UiTMSAT-1 was the name for Malaysia's nanosatellite, MAYA-1 and BHUTAN-1 were the names for the Philippine's and Bhutan's nanosatellites, respectively. These nanosatellites were launched to the International Space Station (ISS) by using the SpaceX Falcon 9 rocket from Cape Canaveral Air Force Station, Florida, USA on June 29th, 2018, and were successfully deployed into the LEO orbit by 'Kibo', the Japanese experimental module, on August 10th, 2018. These nanosatellites had been orbiting and transmitting their beacons in continuous wave (CW) Morse code which had been successfully received by the multiple BIRDS ground stations network.

UiTMSAT-1 went through several developmental stages like any conventional satellite such as mission definition review (MDR), preliminary design review (PDR), critical design review (CDR) and flight model (FM) as shown in Figure 1. As a result of the lean satellite concept approach, the development of UiTMSAT-1 from the project's kick-off until its delivery to the Japan Aerospace Exploration Agency (JAXA) took approximately 15 months compared to the conventional developmental process cycle which had more and complex stages.

Figure 1. Different developmental stages of UiTMSAT-1

The first developmental stage was MDR, which was held about one month after the project's kick-off. In the MDR, a presentation review was done to:

1. Define the main objective of the project.
2. Introduce the team members of the project with task/mission assigned.
3. Discuss the mission proposed for the project.

Each proposed mission went through some considerations of its merits, the mission mode (block diagram and flow chart), the requirement of the mission mode (system requirement, design requirement, and verification requirement), the mission feasibility (as CubeSat had several restrictions in power, size, interface, cost, weight), the key tasks in the development process (design schematic, required environment test), and finally the mission's success levels had to be determined (full, medium, and minimum). At the end of the review, the missions for UiTMSAT-1 were established.

After the MDR, the students worked on the development of the breadboard model (BBM) and individual subsystem test. Following the progress of UiTMSAT-1, a presentation review was conducted at the Preliminary Design Review (PDR) stage. The activities during the PDR presentation included:

1. Make a full Requirement Allocation Sheet (RAS) in a table for all missions and bus system.
2. Present the work breakdown structure (WBS) which included missions, bus system, management, procurement and inventory, integration and testing, integration and testing with a ground station (GS), outreach and advertisement, data distribution, frequency coordinator, safety review.
3. Review flow chart of work plan before and after PDR.

At this PDR presentation stage, the members also presented every mission and subsystem with an updated objective, success levels, block diagram, flow chart and requirement mission mode. Additionally, the test results of the individual and integration functionality of components on the BBM such as the functional test of the flash memory and the connectivity test of the sensor to the MCU, the result analysis and the task schedule before CDR were also discussed. Through this review, the members managed to verify mission feasibility before designing the engineering model (EM) of UiTMSAT-1.

The development of the EM started with the proposed schematic and board design agreed during the PDR. All components, boards, battery box, and the structure were purchased. The developed EM underwent comprehensive requirement testing and the progress was discussed during the CDR presentation. The objectives of this review were to verify the integration mission and subsystem's result before developing the FM. The key points which were reviewed at this stage were:

1. The flow chart of work plan before and after CDR.
2. The updated objective, success levels, block diagram, flow chart and requirement mission mode for each mission and subsystem with detailed schematics on board.
3. The results of the thermal vacuum test (TVT) and the vibration test (VT).
4. The result of the individual (and integration) functionality test of EM.
5. The analysis result for each mission and subsystem.
6. The mission and subsystem's task schedule before FM.
7. The presented end-to-end test (GS-satellite wired or wireless) result.
8. The presented long-distance test (GS-satellite wired or wireless) result.
9. The presented long duration test (GS-satellite wired or wireless) result.
10. The presented antenna deployment test result.

Lastly, the UiTMSAT-1 FM review was conducted. The activity before the review included a re-purchase on the EM design to make minor changes and improvement based on the comments from the CDR stage. With the changes, several testing procedures were re-done such as the space environment tests, the antenna deployment test and the testing of GS-satellite (wireless) which included end-to-end test, long-distance test, and long duration test.

Furthermore, solar simulation test of each solar panel board was also performed to complete the integration of UiTMSAT-1's FM with a solar panel. Despite taking the lean concept approach, the completed FM passed the strict safety requirement review and inspection by JAXA engineers before its delivery to JAXA. This delivery was made possible with detailed supervision via the work breakdown structure planned.

IV. WORK BREAKDOWN STRUCTURE (WBS)

The UiTMSAT-1 project was composed of four divisions as shown in Figure 2. It incorporated the lean satellite concept in the development, service, and crossing work elements to ensure a successful project.

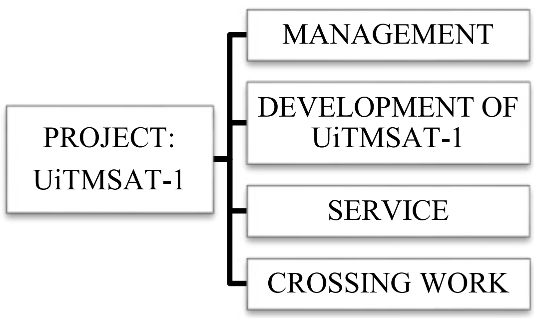

Figure 2. WBS of UiTMSAT-1

A. Management

For UiTMSAT-1, there were two bodies involved in the scheduling management and procurement parts management to maintain the project flow:

1. Laboratory of Spacecraft Environmental Interaction Engineering (LaSEINE),

Kyutech: The development activities of UiTMSAT-1 were centered at LaSEINE.

2. Center for Satellite Communication (UiTMSAT), Faculty of Electrical Engineering, UiTM: Monitored the progress and actively participated at each development stage review.

B. Development of UiTMSAT-1

The development of the UiTMSAT-1 included structure, four subsystems and missions as shown in Figure 3. Its bus subsystems consisted of the communication (COM), the electrical power system (EPS) – main circuitry for nanosatellite power supply, the on-board computer (OBC), the altitude determination and control system (ADCS) part to control the nanosatellite orientation in space. Respecting the lean satellite concept approach, non-space-grade COTS components were used in the development of UiTMSAT-1. The usage of these components reduced the development cost, but it required accepting certain risks related to the chosen components. Nonetheless, specific test procedures were executed to ensure the reliability and good functionality of UiTMSAT-1.

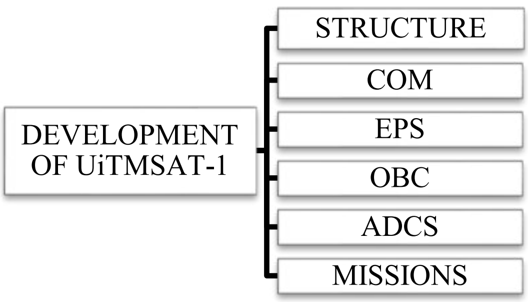

Figure 3. Components in the development of UiTMSAT-1

Figure 4 shows the internal boards' configuration of UiTMSAT-1 that was designed for EM. The design of the boards was based on the missions and systems.

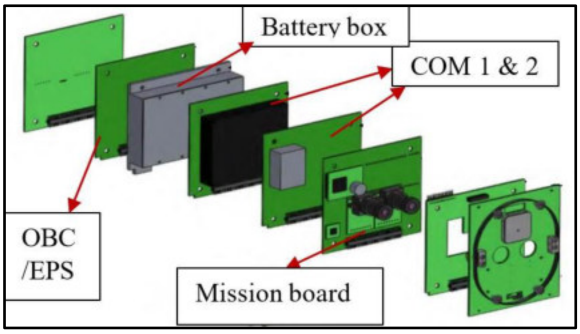

Figure 4. Boards layout of UiTMSAT-1 (Maeda *et al.*, 2017b)

1. On-board computer (OBC)

The roles of the OBC were to organize telecommands, supervise the health status and generate beacon signal for UiTMSAT-1. Its design specification was from the legacy of the HORYU-II and BIRDS-1 satellites of Kyutech (Maeda *et al.*, 2017a). One temperature sensor was assigned to monitor the OBC's temperature as the OBC could only be operated in the range of -55 to +125 degrees Celsius.

2. Electrical power system (EPS)

The UiTMSAT-1's EPS consisted of the battery box and solar panels. Battery played an important part in powering the nanosatellite. The battery would store, regulate and distribute the required power for the whole system and the mission's operation. Hence, it was carefully designed with a special box which fitted six Ni-MH batteries in 3S-2P configuration (3 series, 2 parallel). These batteries had built-in heaters to regulate the thermal constraints in space and temperature sensor for monitoring. Abnormality of the battery sensors' data might indicate a malfunctioning battery.

3. Communication boards 1 and 2

Communication board 1 (COM 1) contained an ultra-high frequency (UHF) transceiver for

UiTMSAT-1's beacon, uplink, and downlink communication. A thermal sensor was placed at this board as part of the housekeeping data. Any anomaly in the data from the sensor at COM 1 would provide an indication about the condition of the communication subsystem. COM 2 functioned similarly as COM 1 where it held the APRS/S&F transceiver for two technology demonstration missions (S&F and APRS digipeater). These missions could not be executed if the COM 2 board was not working.

4. Mission board

The mission board held ADCS and missions related modules such as camera, Global Positioning System(GPS), anisotropic magnetoresistance magnetometer (AMR-MM), APRS digipeater (APRS-DP) and store-and-forward (S&F). These electronic modules would dissipate heat when in use; hence specific rules were required to execute the command. Any temperature irregularity might disturb the function of the mission's module and its technology demonstration purpose. There were six technology demonstration missions which were:

1. Camera: Two camera modules (COTS) installed on UiTMSAT-1 to capture 5 Megapixel (MP) of Earth images of the participating country.
2. Demonstration of a COTS APRS-DP: This technology offered real-time digital communication service to the amateur radio community.
3. Demonstration of an S&F system for remote data collection: Using the terminal node controller (TNC) and very high frequency (VHF) transceiver of APRS-DP, this mission aimed to simulate S&F technique with UiTMSAT-1 capability.
4. Demonstration on the COTS GPS technology: With 80-mW low power GPS, UiTMSAT-1 was capable to display its coordinates in space.
5. Anisotropic magnetoresistance magnetometer (AMR-MM): A sensor onboard the UiTMSAT-1 to measure the magnetic field in space, which offered data coupling possibility with measured magnetic field executed on the Earth's ground.
6. Single event latch-up detection (SEL): Hereditary mission from BIRDS-1, which aimed to observe any correlation of SEL occurrence related to locations and time of the orbiting CubeSat and space weather environment.

C. Development of UiTMSAT-1

Meanwhile, UiTM Shah Alam installed a satellite ground station as Malaysia's satellite Earth station for the overall BIRDS project. This would be further discussed in section V.

D. Crossing Work

Crossing work division involved the integration of the developed satellite for complete testing. Comprehensive testing procedures included integration testing with UiTMSAT-1 subsystems and missions, plus the integrated testing between the UiTMSAT-1 and a ground station (GS).

The development, assembly and testing processes were done at LaSEINE of Kyutech. The assembly process of UiTMSAT-1 was done inside Kyutech's clean room. Several testing procedures were carried out based on the specified environmental requirement to fit the safety review requirement for nanosatellites. Aligned with the lean satellite concept in its risk-taking and short delivery time approaches, UiTMSAT-1's space radiation test was not carried out, but two significant tests were conducted to verify that the developed model of UiTMSAT-1 fulfilled the qualification requirement. The specific tests conducted were the thermal vacuum test and the vibration test.

Based on the Japanese Experiment Module (JEM) Payload Accommodation Handbook Small Satellite Deployment Interface Control Document (JAXA 2015), the environmental conditions for thermal and vibration were:

1. Thermal environment
   i. In H-II Transfer Vehicle (HTV): +5 ~ +32 degrees Celsius
   ii. SpaceX: +18.3 ~ +30 degrees Celsius

2. Vibration (Launch) environment
   i) H-II Transfer Vehicle (HTV): 8.34 g
   ii) SpaceX: 8.67 g

The main purposes of the thermal vacuum testing were to meet the qualification requirements under vacuum condition and extreme temperature, besides the thermal stressing environment. The machine would reproduce the extreme hot and cold temperatures in the vacuum condition of space. Functionality test of the UiTMSAT-1 was performed before, during and after the TVT to ensure the satellite could withstand the environment and pass the functionality test.

Another test done on UiTMSAT-1 was a vibration test. By utilizing the HTV and SpaceX launch vehicle profiles, UiTMSAT-1 went through the vibration testing process to confirm it could endure the launch condition. The satellite experienced vibrations and loads comparable to the assumed condition on the launch. This testing ensured the condition of UiTMSAT-1 and its functionality after the launching.

Additionally, UiTMSAT-1 also underwent several other integration testing procedures such as the functionality test (individual and integrated subsystem), screening battery test, fit (frame) test using J-SSOD, antenna deployment test using the despatch chamber, radiation pattern test in an anechoic chamber, radiation test at Kyushu University in Japan, solar panel assembly and the Solar Simulation test. The integration testing of UiTMSAT-1 with a ground station included the end-to-end test (wireless) for near and far distance, anechoic test, long distance test at a 5-km distance (between the ground station at Kyutech and Mount Sarakura in Japan) and long duration test (one-week test with solar simulator).

V. UiTM GROUND STATION

The UiTM ground station was installed at UiTM Shah Alam, Malaysia to support UiTMSAT-1's monitoring and the BIRDS-2 project. It has been in operation since December 2017. The ground station employed amateur radio frequency and had two different Yagis. These antennas operated in the range of 144 - 148MHz for the VHF Yagi antenna and 430 - 438MHz for the UHF Yagi antenna.

The UiTM ground station is a member of the BIRDS Ground Station Network with its main mission in monitoring BIRDS-2 nanosatellites. Besides UiTM's GS and Kyutech's GS, the BIRDS Ground Station Network consisted of another eight participating countries of the BIRDS Project (Pradhan *et al.*, 2018) as illustrated in Figure 5. All the GS members have been monitoring and updating the health status of UiTMSAT-1, MAYA-1, and BHUTAN-1 nanosatellites since their deployment. The Lean satellite concept with its low-cost approach was used in the design of the satellite ground station. The use of amateur radio frequency bands in the ground station setup allowed lower cost in comparison with the commercial communication radio frequency bands. Additionally, more satellite's data could be obtained effortlessly with this network of ground stations.

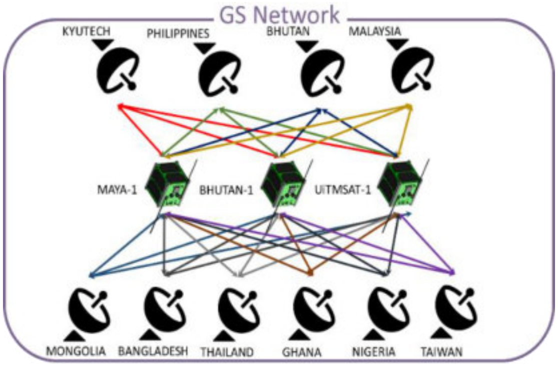

Figure 5. BIRDS ground station network

Among the devices and equipment installed at the ground station were:

1. ICOM 9100 Radio Transceiver.
2. G-5500 Rotator and GS-232 Computer Interface Rotator.
3. Terminal Node Control (TNC): TNC was connected to the ICOM radio transceiver, it was also connected to the control PC using USB interface. It had several units of LED that worked as an indicator for each receive and transmit activity generated from the satellite and control PC.

During the time the satellite passed over the station, with guidance from SATPC32 for satellite tracking, the ground station operator could receive several CW Beacons of the tracked satellite. The UiTM ground station had a few computer softwares to aid the beacon capturing process. For example, CWGet, this was the software to decode the satellite's CW Morse code beacon via sound card into readable text. Its set up only needed a radio/receiver and computer with a sound card. The readable Morse code character was displayed for the operator to do further analysis. Figure 6 shows a screenshot of the CWGet software.


Figure 6. UiTMSAT-1's beacon reception display on CWGet. The dotted box was zoomed-in to display the text "BIRDMY". BIRDMY was the UiTMSAT-1's satellite identification

VI. PRELIMINARY OBSERVATIONS: HOUSEKEEPING (HK) DATA

The BIRDS-2 nanosatellites were monitored at the UiTM ground station day and night. The satellite tracking operation was scheduled by the BIRDS-2 members. The schedule allowed the ground station operator to track nanosatellites alternately between UiTMSAT-1, MAYA-1, and BHUTAN-1; one chosen nanosatellite per day. The HK data observations were done by analyzing the CW Morse code beacon for UiTMSAT-1 nanosatellite specifically since its deployment. The analysis was useful for improving future satellite building. The CW Morse code beacon had 20 Hex characters that carried the satellite's health status. The beacon transmission was a repetitive process which went on for 30 seconds and was silent for 85 seconds for the transmission command from the ground. With 435.375MHz as the communication frequency, the CW beacon transmitted at a rate of 20 words/min (Maeda *et al.*, 2017a).

The plottings presented in Figures 7-9 were specifically for UiTMSAT-1 with each parameter of the HK data observed; which were the observations on UiTMSAT-1's battery temperature, OBC temperature and battery voltage, respectively.

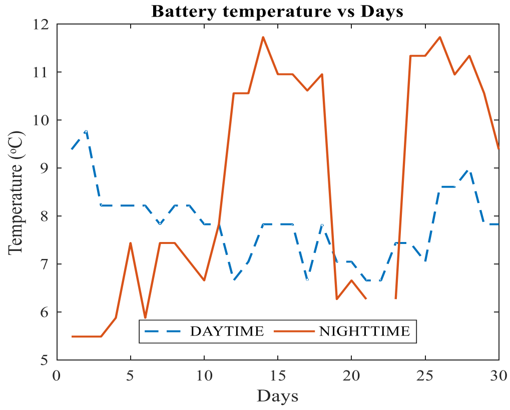

Figure 7. UiTMSAT-1's battery temperature observations

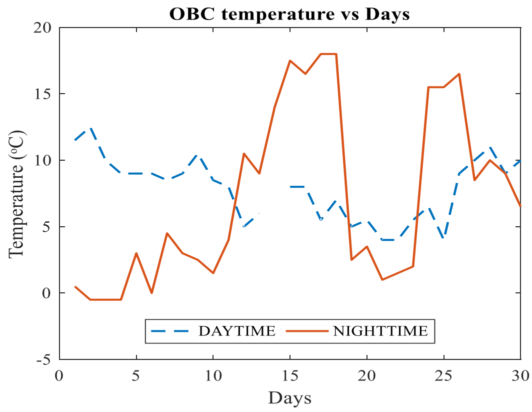

Figure 8. UiTMSAT-1's OBC temperature observations

Based on Figures 7 and 8, the difference between the temperature values of the battery and the OBC varied slightly between nighttime and daytime. One main contributor to the temperature value was the electronic activity and usage of the satellite components which it would generate heat such as the OBC's MCU processing component inside the UiTMSAT-1. Besides, the external surface of the nanosatellite was hotter than the internal area during daytime due to sunlight exposure. With the extreme temperature and vacuum conditions of the space environment, it took some time for the satellite to reach equilibrium. Hence, the heat transfer process from the hotter external to the colder internal occurred slowly. Therefore, if the next satellite passing occurred during the eclipse period or at nighttime, the decoded data would show an increased value compared to the daytime.

Another parameter observed was the battery voltage of UiTMSAT-1 as given in Figure 9. The HK data showed that the voltage was higher during the daytime. This was due to the satellite's battery and solar panel operating. When the satellite received sunlight, the power supply was switched to the solar panel component. The UiTMSAT-1's solar panel was generating the required power for the satellite operations and for charging the satellite's battery with the received sunlight. Hence, the overall battery voltage increased. In contrast, the solar panel was not active during the nighttime, and the operational power was supplied from the charged battery. This discharge activity caused an increase in the current flow thus showing an increased current value for the battery and lowered the battery voltage – based on Ohm's law. This discharge process also dissipated heat and contributed to the higher value of a battery's temperature.

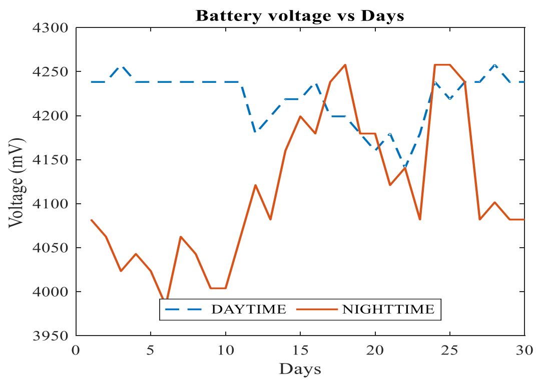

Figure 9. UiTMSAT-1's battery voltage observations

VII. CONCLUSION

As UiTMSAT-1 was the first nanosatellite launched into space by Malaysian academic operators, this project stressed on technology development and demonstration. It involved a multinational collaboration and applied the lean satellite concept approach. Based on the fast delivery of UiTMSAT-1 and the design with non-space-grade COTS components, the lean satellite concept approach was exhibited. UiTMSAT-1's HK preliminary results analyzed at the UiTM ground station also supported the accomplishment of the lean satellite concept approach.

VIII. ACKNOWLEDGEMENT

The work was supported by JSPS Core-to-Core Program, B. Asia-Africa Science Platforms, *Dana Kecemerlangan Akademik* UiTM and the Ministry of Education, Malaysia. The authors would like to extend their appreciation to the BIRDS-2 members and collaborators for their great support and guidance.

IX. REFERENCES

[1] Addaim, A, Kherras, A and Zantou, EB 2007, 'Design of Store and Forward Data Collection Low-cost Nanosatellite', in *2007 IEEE Aerospace Conference*, 3-10 March 2007, Big Sky, MT, USA.

[2] Addaim, A, Kherras, A and Zantou, EB 2008a, 'Design and analysis of store-and-forward data collection network using low-cost LEO Nanosatellite and intelligent terminals', *Journal of Aerospace Computing, Information, and Communication*, vol. 5, pp. 35–46.

[3] Addaim, A, Kherras, A and Zantou, EB 2008b, 'DSP implementation of integrated store-and-forward APRS payload and OBDH subsystems for low-cost small satellite', *Aerospace Science and Technology*, vol. 12, pp. 308–317.

[4] Boshuizen, CR *et al.* 2014, 'Results from the Planet Labs Flock Constellation', in *28th Annual AIAA/USU Conference on Small Satellites, 4-7 August 2014*, Utah, USA.

[5] Cho, M & Fukuda, H 2017, 'Flight results of new technology onboard a lean satellite HORYU-IV', in *International Proceedings of IEEE Region 10 Conference (TENCON), 22-25 November 2016*, Singapore.

[6] Cho, M, Hirokazu, M & Graziani, F 2015, 'Introduction to lean satellite and ISO standard for lean satellite', in RAST 2015 – in *Proceedings of 7th International Conference on Recent Advances in Space Technologies,16-19 June 2015*, Istanbul, Turkey.

[7] Japan Aerospace Exploration Agency (JAXA) 2015, *JEM Payload Accommodation Handbook Small Satellite Deployment Interface Control Document*, vol. 8, pp. 1–101.

[8] Maeda, G *et al.* 2017a *BIRDS Project Newsletter*, no. 15, viewed 1 September 2018, <http://birds.ele.kyutech.ac.jp/>.

[9] Maeda, G *et al.* 2017b, *BIRDS Project Newsletter*, no. 21, viewed 1 September 2018, <http://birds.ele.kyutech.ac.jp/>.

[10] Mahmood, R *et al.* 2011, 'ICUBE-1: First Steptowards Developing an Experimental Pico-satellite at Institute of Space Technology', *Journal of Space Technology*, vol 1, no. 1, pp. 5–10.

[11] Masui, H *et al.* 2015, 'Activity and strategy for lean satellite in Kyushu Institute of Technology', in *RAST 2015 - Proceedings of 7th International Conference on Recent Advances in Space Technologies, 16-19 June 2015*, Istanbul, Turkey.

[12] Mehrpavar, A *et al.* 2014, *Cubesat design specification*, The CubeSat Program, California Polytechnic State.

[13] R. Khan, A *et al.* 2015, 'Five-nations CubeSat Constellation; An Inexpensive Test Case for Learning and Capacity Building', in *3rd IAA Conference on University Satellite Missions and CubeSat Workshop& International Workshop on Lean Satellite Standardization, 30/November - 5/December 2015*, Rome, Italy.