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BIRDS-2: Multi-Nation CubeSat Constellation Project for Learning and Capacity Building

Kiran Kumar Pradhan, BIRDS-2 members, BIRDS Partners, Faure Pauline, George Maeda, Sangkyun Kim, Hirokazu Masui, Mengu Cho
Kyushu Institute of Technology
1-1 Sensuicho, Tobata, Kitakyushu, Fukuoka, Japan; +81-(0)93-884-3229
pradhan.kiran-kumar901@mail.kyutech.jp

ABSTRACT

The BIRDS project began in October, 2015 with an objective to provide hands on experience to the graduate students on satellite technology. In a BIRDS project, the students define missions, design, build, test, and operate satellite within given time frame of the project. A 1U CubeSat is built per participating country which are then released from International Space Station (ISS) into Low Earth Orbit (LEO) and operated through a ground station network, with one ground station established in each member nation. That being the first is series, the second BIRDS project or so called BIRDS-2 project started in November, 2016 with students from, Philippines, Bhutan, Malaysia and Japan. Lean philosophy is adopted for the development of CubeSats and an overlap of a year is created between successive projects so that the lessons learned and knowledge gained from each project is properly passed on. The BIRDS program targets to improve the development process of a CubeSat while maintaining/improving the reliability and reducing waste. But the true success of the program is indicated by the ability of project members to replicate what they learn from this project, at their home country after graduating.

INTRODUCTION

The space industry experienced an exponential growth in the number of satellites launched since 2013[6]. University built satellites, most commonly CubeSats, has been a major contributor in this statistics[7]. The significance of small satellites have been undeniable and the increase in launch of such satellites indicates global acceptance of the SmallSat/CubeSat technology for the advancement of the space industry. One such significant feature of the CubeSat is feasibility of low cost and short time development which has not only enabled universities and developing countries to build their own satellites but also, it has served as a very efficient means of capacity development of young engineers.

The Joint Global Multi-Nation Birds (JGMNB) project or simply BIRDS project, not only takes advantage of the features of CubeSats like, low cost and short time development but also it provides platform for developing countries to build and launch their own satellite. In addition to having your own satellite placed in to orbit, each country also gets to train engineers who would later be the integral part of the space program in each nation.

The BIRDS project was initiated in the Laboratory of Spacecraft Environment Interaction Engineering (LaSEINE) of Kyushu Institute of Technology (KyuTech) located in Kitakyushu City under Fukuoka Prefecture, Japan. The project kicked off in October, 2015 with 15 students from six countries (Japan, Ghana, Mongolia, Nigeria, Bangladesh and Thailand). KyuTech collaborated with universities from six other countries and 5 1U CubeSats were developed belonging to Japan, Ghana, Mongolia, Nigeria and Bangladesh. Thailand and Taiwan were only Ground station partners. The five flight models (FM) of BIRDS-1 project is shown in the figure 1. The students defined the missions, designed the subsystems, carried out all the procurements required, assembled and integrated the CubeSats, conducted all necessary tests, and delivered the satellites to the launcher. Once the satellites are placed in the orbit, the students also operated the satellites.

Mission Statement

The project aims to provide students with a hands on experience on the overall cycle of satellite development process starting from defining missions to decommissioning of the satellite. But it does not end there. The true success of the project is defined by the achievement of each member after completion of the project and graduating from KyuTech.

The mission statement of the BIRDS project states, "By successfully building and operating first satellite of nation, advance toward indigenous space program in each country[1,3,4]." Because for some of the countries, the satellite build with this program is the first for their country. But, since it is not the case for some, so in general the mission statement can be modified as, “By successfully building and operating a CubeSat, advance toward indigenous space program in each country”. The students are mandated to build upon the experience gained at KyuTech through BIRDS program for the development/advancement of space program in their own country.

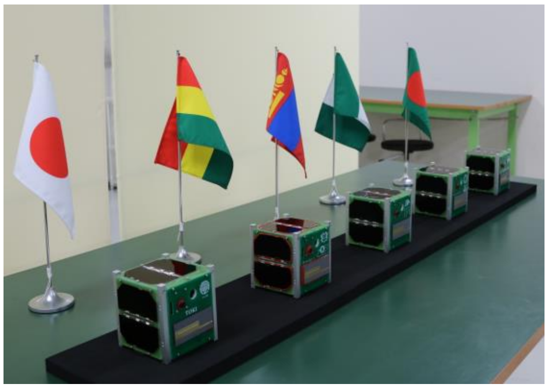

Figure 1: Flight models of BIRDS-1 project

Objectives

As it might be clear by now, the main objectives[1,3,4] of the BIRDS program is as stated below:

1) Learn the entire processes of a satellite program from mission planning to satellite disposal

2) Lay down foundation of sustainable space program by accumulating human resource in universities and launching a university space research and education program

3) Create international human networks for the infant space programs to assist each other

Five 1U CubeSats developed by the BIRDS-1 team were launched to ISS with the SpaceX cargo ship (CRS-11) on June 3, 2017 and they were subsequently release into the orbit on July 7, 2017 by the Japanese Kibo module. For Mongolia, Ghana and Bangladesh, it was the first satellite of their nation. But this paper will focus on the successor project in the BIRDS program, the BIRDS-2 project. And author’s experience of becoming part of BIRDS family since the kick-off of BIRDS-2 project is shared in this paper. The BIRDS project was awarded the GEDC Airbus Diversity Award in 2017[10].

IMPLEMENTATION OF BIRDS-2 PROJECT

BIRDS-2 is second project in series of the BIRDS program which kicked off in November, 2016. Students from four countries constituted the project team, three from Japan, four from Bhutan, two from Malaysia and two from Philippines making up the eleven member team. Although four nations were involved, only three 1U CubeSats were developed, one each for Bhutan, Malaysia and Philippines.

Typically, each BIRDS project is designed to be completed within 2 years, including operation of the satellite. And successive projects begin after a year from the beginning of the previous project. Thus, there is an overlap of a year created between the projects. This project started when the BIRDS-1 project was midway through the development of their spacecraft. The reason for this is to effectively transfer the knowledge gained and the lessons learned from each project to the successive projects in an effort to improve the development process of future spacecraft. This is one of the initiative that aids in Lean Satellite approach which is discussed later.

From the kick off, the team was engaged in defining the missions for their CubeSats. This process involves extensive consultation with stakeholders from each country. Like in any satellite program, understanding the stakeholder’s requirement is a key step as they fund for the spacecraft. The v-model for systems engineering and verification is adopted and the students are trained to gain specialized system engineering experience enabling them to initiate space program of their own country[3].

BIRDS-2 Missions

After about two months of consultation and review process, the final shortlist of missions where determined which was then presented during the Mission Definition Review (MDR) held towards end of December, 2016. As an outcome of the MDR, following missions were adopted for BIRDS-2 project:

1) Automatic Packet Reporting System Digi-peater (APRS-DP)

2) Store and Forward demonstration (S&F)

3) COTS Camera (CAM)

4) COTS GPS Demonstration (GPS)

5) Anisotropic Magneto Resistance Magnetometer (AMR-MM)

6) Single Event Latch-up (SEL)

Within each BIRDS project, all the CubeSats are developed to be identical. For BIRDS-1, all five CubeSats had same missions. Similarly, for BIRDS-2, all three CubeSats are designed with same configuration and shall perform same missions as stated above. Each of the missions are briefly described in the following paragraphs.

The BIRDS-2 CubeSats carries a VHF transceiver capable of handling APRS packets. When the mission is turned on, the amateur community can send a text message to the satellite which in turn will broadcast the message within its coverage area. All amateur users capable of handling APRS packets will be able to receive it. The radio used is shown in figure 2. This mission demonstrates the performance of commercially available APRS radio in space and potential future application is seen in the disaster relieve operations for emergency communications. The radio used as payload is manufactured by Radiometrix Ltd. and operates at 145.825 MHz frequency.

Figure 2: VHF transceiver payload of BIRDS-2 project

Using the same hardware of the APRS-DP mission, the three CubeSats of BIRDS-2 project will also demonstrate the S&F capability of a CubeSat. The focus is on building a low cost Ground Sensor Terminal (GST). The data collected by the sensors at remote locations on earth will be transmitted by the GST to the satellite as it approaches and the data is then downloaded to the central ground station from the satellite by command.

Similar to BIRDS-1 CubeSat, the BIRDS-2 CubeSat will also carry Commercial off the Shelf (COTS) camera module. Each CubeSat will carry two identical camera modules as shown in figure 3, the OV5642 sensor which is capable of taking images of 5 MP. But the lens used for each module is different. One of the module will use a narrow angle lens with focal length of 25mmand will provide images with spectral resolution of approximately 25m. While the other module will make use of a wide angle lens with focal length of 8mm, to provide images with spectral resolution of about 82m. The objective of this mission is to capture images of each participating country from space. Also, all three CubeSats will take a short video right after release from ISS.

The BIRDS-2 CubeSat will also demonstrate performance of a low power COTS GPS module for the first time in space. Figure 4 shows the GPS chip which is mounted inside the satellite and uses a patch antenna to lock the signals. If successful, the low power consuming GPS module, Venus838FLPx-L, could become a great asset for future CubeSat missions.

Figure 3: Camera module used in BIRDS-2 project

Each CubeSat will have an AMR magnetometer, HMC5883L, on board which will be collecting the earth's magnetic field data every 10 seconds on the orbit. These data will be later compared with the magnetic field data collected on the earth surface.

Figure 4: GPS module used in BIRDS-2 project

And finally, BIRDS-2 CubeSats will continue with the SEL mission from BIRDS-1 which actually began from the HORYU-4 microsatellite built by KyuTech. This mission originated as a lessons learned from the operation of HORYU-2 microsatellite of KyuTech which experienced multiple reset events of On-Board Computer (OBC). The suspect was the occurrence of SEL events[8] and thus, protection circuits were included in the electric bus system of HORYU-4 to protect the spacecraft from latch up events and record occurrence of such event. The same system was implemented in BIRDS-1 CubeSats[4] and now will be implemented in BIRDS-2 CubeSats.

Satellite Bus System and Configuration

The bus system for BIRDS program is customized on the flight proven bus configuration of HORYU-2 and HORYU-4 developed by KyuTech. Thus, the spacecraft of BIRDS-2 project adopted the CubeSat bus system of BIRDS-1 with little modification. For that reason, the team studied the bus system of BIRDS-1 spacecraft in parallel to the task of defining missions so that by the time missions were defined, each member were assigned with a task and were aware of where to begin. Work breakdown structure (WBS) and product breakdown structure (PBS) were developed based on missions to assist in assignment of tasks to each member within the project.

Four aluminum rail type chassis is used to provide support to the CubeSat structure. The so called backplane type layout is adopted similar to that of UWE-3 CubeSat made by University of Wurtzburg, Germany[2]. A PCB, called as backplane, which acts as an interface for all other subsystems is mounted at the base of the aluminum cage as shown in the figure 5. All other boards are mounted on the backplane via a 50 pin connecter and it serves as both the data and power bus for the CubeSat. This configuration significantly reduces the use of harnesses which complicates the layout. Once all the boards are placed on backplane, four rods, which goes through each board, is used along with spacers between boards to provide rigidity to the structure.

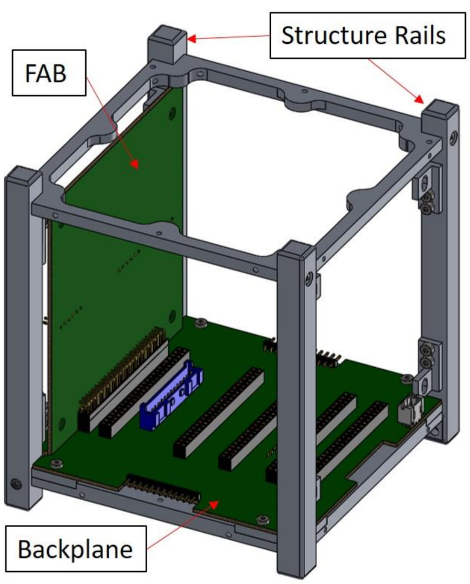

Figure 5: BIRDS-2 Structure with backplane mounted on it

The satellite is powered by six Nickel Metal Hydride (NiMH) batteries placed inside an aluminum box and connected to the backplane using a 14 pin connector. With lessons learned from the BIRDS-1 operation, a small sheet heater is placed inside the battery box. It will be turned on, in case the temperature of the batteries drop below 6°C in order to maintain the temperature above 0°C for the batteries to operate efficiently. Ten solar cells, two each on five sides, are used to charge the battery during sunlit period. The integration of solar cells onto the PCB is carried out by project members in-house, even if it is considered a very skilled job as the solar cells are expensive and a slight error can lead to wastage of two solar cells. A Microchip (PIC) microcontroller, named as RESET PIC, has master control over all the power supply and monitors the current flow on each of the supply line with the help of an over current protection circuit.

The On-Board Computer (OBC) subsystem consists of two Renesas H8 Microprocessors (Main H8 and Com H8) and one PIC microcontroller (CW PIC). Main H8 has the role of handling command and data of the spacecraft and also has control over power supply lines to other subsystems. The role of the COM H8 has been greatly reduced as compared to BIRDS-1's design[3,4]. Its major function is to generate morse code for housekeeping (HK) data and has a control over the beacon transmission. The call sign for the beacon is generated by the CW PIC and it functions like an independent subsystem such that even if the two H8s encounter issues, the CW PIC will continue to generate the call sign and keep transmitting it to indicate the satellite is alive. Com H8 has the ability to temporarily stop the beacon transmission, if required, to carry out missions or other operations.

Major changes were introduced on the communications subsystem (COM) for BIRDS-2 as compared to the BIRDS-1 COM subsystem[3,4]. A UHF transceiver is used with 9600 bps baud rate and GMSK modulation for both uplink and downlink while BIRDS-1 used VHF band for uplink with 1200 bps baud rate. The COM board for BIRDS-2 has a separate module, internally, for beacon transmission and is controlled by the CW PIC but the UHF transceiver itself is controlled by a separate PIC microcontroller called COM96 PIC. Deployable monopole antennas were selected as opposed to patch antenna of BIRDS-1 since the gain provided by the patch antennas were not sufficient.

A UHF monopole antenna for the COM subsystem and a VHF monopole antenna for the APRS-DP mission are coiled on one of the side of the CubeSat which is used for camera lens to point outwards. A nichrome wire burner circuit is used to cut the fish string which holds the antennas stowed during launch and release from the ISS. RESET PIC has the important role to prevent antenna deployment and RF emission until 30 minutes of release from ISS.

As popular with CubeSats that has been previously launched, BIRDS-2 also uses passive attitude control system. The Attitude Determination and Control System (ADCS) consists of permanent magnets and hysteresis dampers to stabilize the tumbling. A PIC microcontroller, named as ADCS PIC, continuously takes reading from a gyroscope and solar cells as coarse sun sensor to determine attitude. ADCS PIC is also responsible for collecting the data from magnetometers and the GPS as part of mission. Despite having a GPS on-board, it will not be used as part of the ADCS subsystem, since it is first flight for the GPS module and the team decided not to take any risk that might occur depending on it. A summary of spacecraft bus system is provided in the table 1.

Table 1: BIRDS-2 spacecraft bus configuration

Sl. No	Bus System	Configuration
1	On-Board Computer (OBC)	- Renesas H8 36057F - PIC16F1787 - Main Data Protocol: SPI
2	Electric Power System (EPS)	- NiMH battery: 6 eneloop+ - Supply: 3.3V, 5V, Unregulated - Nominal Power: 2 W - Peak Power: 4 W - Solar cells: 10 Body mounted
3	Communications System (COM)	- Downlink: UHF - 437.375 MHz - GMSK, 9600 bps - Uplink: UHF - Antenna: Monopole
4	Attitude Determination and Control system (ADCS)	- Passive control - Permanent magnets - Hysteresis dampers - Gyroscope - Magnetometers - Solar cell readings

So far, six microcontrollers have been introduced that has been used in various subsystems of BIRDS-2 spacecraft. That is quite a lot for a 1U CubeSat but that's not it, each BIRDS-2 CubeSat has two more microcontrollers placed inside. One ATmega2560 microcontroller, called CAM MCU, is used for the camera mission, responsible for executing commands to take images and store them. Another PIC microcontroller, termed APSF PIC, is used for the APRS-DP and S&F missions. The layout of the subsystems and their boards inside the CubeSat is discussed in more detail in the paragraphs to follow.

As already discussed earlier, backplane serves as a backbone for all other boards. The first board, as indicated in the figure 6, is the front access board (FAB), which hosts the remove before flight (RBF) pin and programming pin access to three microcontrollers of OBC. Next to FAB is the OBC/EPS board. As the name suggests, the OBC subsystem and the electric power supply (EPS) subsystem is fabricated in this board. Along with the FAB and backplane, OBC/EPS board is fabricated by a Japanese company who also serve as a design partner for those boards. Next to the OBC/EPS board, battery box is attached to the backplane using a JST connector.

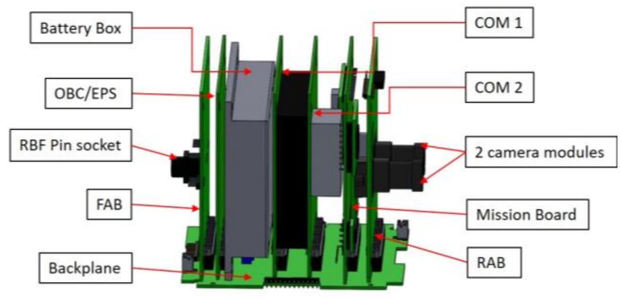

Figure 6: BIRDS-2 project boards layout

Adjacent to the battery box, the COM board with UHF transceiver is placed. Heat generated by the transmitter is expected to aid in keeping the temperature of battery box above 0°C. Next to COM board, the payload for APRS-DP and S&F mission, the VHF transceiver, is positioned and its termed COM-2 board. Following the COM-2 board, the Mission Board (MB) is placed. The MB hosts the ADCS subsystem, camera mission subsystem, COM96 PIC for COM and APSF PIC and the terminal node controller (TNC) for APRS-DP and S&F mission. The GPS module and magnetometer is also mounted onto the MB following which is the rear access board (RAB) which provides the access to programmer pins of all microcontrollers except for the three microcontrollers of OBC. RAB serves as interface between the MB and the burner circuit for antenna deployment and also between one of the solar panel board and backplane. Rest of the solar panel boards connect directly to the backplane using header pin connection.

Space Qualification Tests

Following the usual practice for CubeSats, the two key space qualification tests conducted on the flight models (FM) of BIRDS-2 are thermal vacuum test (TVT) and vibration test (VT). All the test facilities are available at the center for nano-satellite testing (CeNT) in KyuTech[11].

The TVT was conducted prior to the VT as the satellite was not fully assembled during the TVT. Few thermocouples were used to get temperature readings from inside of the satellite at the time of test, thus one of the side was closed using only kapton tape instead of screws. The antennas were at deployed state to enable communications between the satellites and dummy ground station that was used to conduct the functional tests. The three FMs were put through two hot and cold cycles with temperatures ranging from -15°C to 60°C. A round of functional test was carried out at each extreme temperature with 30 minutes of prior soaking time. The figure 7 indicates the setup of FMs inside thermal vacuum chamber.

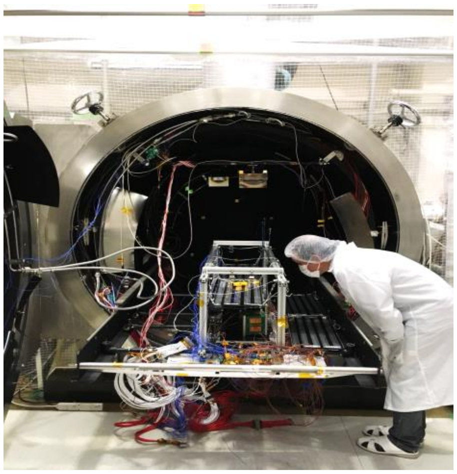

Figure 7: BIRDS-2 FMs ready for TVT

The CubeSats of BIRDS projects are contractually bound for ISS release, thus the launch environment is considered to be less severe and options of the rockets available for launch to ISS is known beforehand. As required by any launcher, random VT on all axis of the satellite were conducted to meet the acceptance level. For the purpose of VT, a pod has been developed similar to J-SSOD which can fit up to three 1U CubeSats or one 3U CubeSat as shown in the figure 8.

Other major tests performed on the FMs were the extended functional test with actual ground station, long distance test to confirm the link budget calculated and the long duration end-to-end test designed as a rehearsal for the actual on-orbit operation. Some other tests performed on the engineering models (EM) are discussed briefly in the next paragraph.

Antenna radiation pattern test were performed extensively on EM in the anechoic chamber. The UHF radio and VHF radio characterization were also conducted in the chamber. Radiation tests were performed on the GPS module, camera module and few samples of H8. The antenna deployment mechanism was tested comprehensively in the most extreme conditions to ensure the probability of success of deployment on-orbit is close to 100%.

Development phases and Current status

Having determined the missions, the team tested and verified the designs by developing bread board model (BBM) and it was then reviewed at Preliminary Design Review (PDR) which was held at the end of March, 2017. With Critical Design Review (CDR) scheduled in mid of July, 2017, the team then developed the engineering model, which was later termed as EM-1. But, because of some issues with the design and some major changes foreseen, the team could not conduct a complete round of environment test on EM-1.

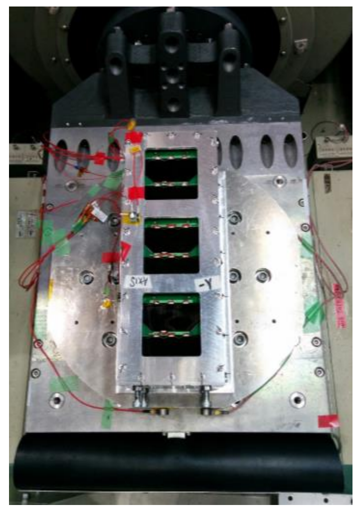

Figure 8: Three BIRDS-2 FMs setup for VT

Incorporating the changes, the team then worked towards designing and developing the second engineering model called EM-2. For that reason, a second Critical Design Review (CDR-2) was scheduled towards end of October 2017. Then, having sorted out the design issues, the team received the go ahead signal for developing the flight models (FM). Prior to the assembly of FMs, the solar cells were attached to the solar panel boards and left for curing. Then, with all the parts and components (including boards) prepared and properly inspected, the FMs were integrated with members from each country working on their own satellite. The three FMs were ready for delivery to the launcher by end of February 2018 having gone through all the qualification tests required.

But the team encountered a small hitch towards the delivery of satellites. Only as the time for delivery approached, it was known that the pre-license and call sign for the CubeSats were not obtained yet and also, there was a delay in the ITU API publication. For these reasons, the launcher could not accept the satellites at that moment and it remained inside the clean room of KyuTech for little more than 2 months.

With all the procedures complete, three CubeSats of BIRDS-2 project were finally delivered to JAXA by mid May 2018. And currently, at the time of submission of this paper, the satellites await launch to ISS, which is scheduled at the end of June, 2018 and subsequent release to orbit is expected in the following month. Figure 9 shows the three FMs of BIRDS-2 project and table 2 has the satellite name and call sign of each CubeSat.

Table 2: BIRDS-2 satellite name and call sign

Country	Satellite name	Call sign
Bhutan	BHUTAN-1	JG6YKL
Philippines	MAYA-1	JG6YKM
Malaysia	UiTMSat-1	JG6YKN

GROUND STATION NETWORK

Once the CubeSats are released into orbit, the BIRDS-2 team members will operate them from the KyuTech ground station. A custom software has been developed using Microsoft Visual C# similar to BIRDS-1 for the uplink of commands and capturing downlink data. In the initial phase, all three CubeSats will be close to each other and that will complicate the operation of the satellite since they utilize same frequency. To tackle that issue, the CubeSats have been programmed to transmit beacon signals in alternating manner so that it is easy to decode signals at the ground station. Also, the commands include call sign of the satellite it is intended for, so thus the satellite knows if it should execute the command or not. In addition, there is a command which can make the satellite stop their RF emission for few minutes so that operation can be focused on one satellite.

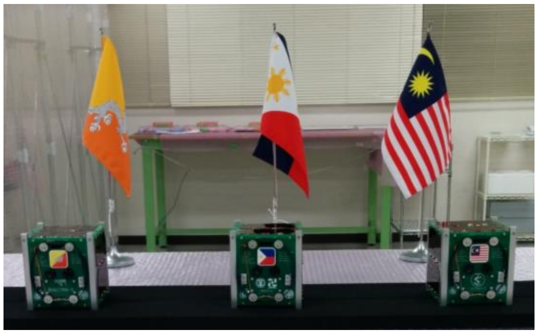

Figure 9: Flight models of BIRDS-2 project on display

The 3 CubeSats will also be operated through the Ground Station Network (GSN) of the BIRDS program. The BIRDS-1 had 7 member nations with 2 of them providing only the ground station services. Identical ground stations where developed in BIRDS-1 member countries: Japan, Ghana, Mongolia, Bangladesh, Nigeria, Thailand and Taiwan. The ground station for BIRDS-1 is also replicated in the member nations of BIRDS-2, Bhutan, Malaysia and Philippines, although there will be a slight modification in the operation of the ground stations. So currently, there are 10 ground stations members in the BIRDS GSN and the figure 10 shows the ground station members and operation plan.

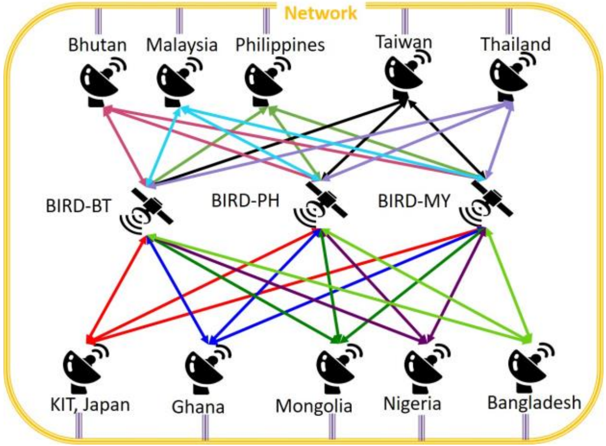

Figure 10: Ground Station Network operation plan of BIRDS program

Ground stations in each country is connected with each other via a ground station network device which has been developed in partnership with a Japanese Start-up, Infostellar Inc. The device consists of a data transfer module and a software defined radio (SDR). It enables collection of data from each of the ground stations and store it at central server. The device also gives access to central server to control local ground station equipment remotely. The central server will be located at KyuTech[5]. With the GSN, communications time between ground station and the satellites is drastically increased. A higher throughput in the downlink data can be obtained through this network.

LEAN PHILOSOPHY

It is believed that the essence of small satellites is not their size or mass but the philosophy of development that relies on building satellites faster and cheaper[9]. So the “lean” terminology was adopted by a group of international experts in 2014 to define satellites that are built utilizing untraditional risk-taking approach for fast delivery with low cost and small team[6].

BIRDS program experiments the concept of lean satellite approach which aims to deliver value to the end-users at minimum cost and shortest possible time by minimizing waste. In addition, this approach targets to achieve maximum reliability within the given budget and schedule constraints. Students are expected to adopt the lean approach for their national space program so that the program is sustainable with a small team and minimum cost.

When a BIRDS project begins, all students are kept in the same room so that there is more face to face communication as opposed to relying on emails. All the facilities necessary for the development of a satellite is available within 30m radius. The figure 11 shows the BIRDS project development facility within KyuTech. The facilities are spread across two buildings. The students are placed in a room where they do most of the development work and it is situated in the same building with the clean room and the CeNT. The shaker table and the thermal vacuum chambers are located in the ground floor and that reduces the time required for moving the satellites for testing. The anechoic chamber and the ground station is located in the other building but still at a very close proximity.

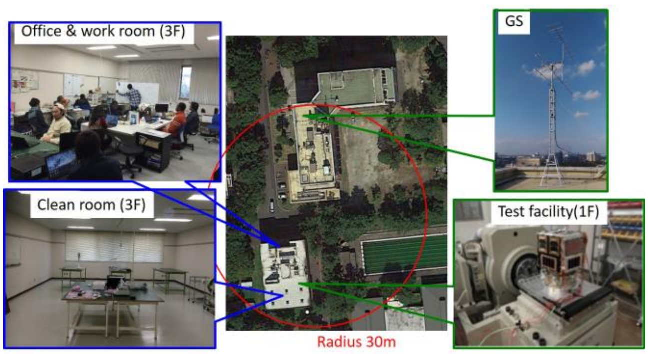

Figure 11: BIRDS project development facility setup inside KIT campus

Only facility not available within the campus is the radiation test facility but since the need for radiation testing in a CubeSat project is subject to very few selected components, testing requirement and time spend is very minimal. So, during the whole process of development, there is no need for the CubeSats to go out of that 30m radius except for the time of long distance test whereby the satellite is taken to a nearby mountain top to emulate the on-orbit scenario. Overall the setup is ideal for minimizing waste of time, usually incurred in moving the spacecraft or components for test or any other purposes.

CONCLUSION

Five 1U CubeSats of BIRDS-1 were launched and released to orbit in 2017. The lessons learned have been implemented in the BIRDS-2 CubeSats and the three 1U CubeSats currently await their launch to ISS. Meanwhile, BIRDS-3 project has kicked off with 3 nations, Japan, Sri Lanka and Nepal. Lessons learned from both the previous projects will be transferred to the new project while they will also implement changes to the hierarchy of bus system, brought upon by the advancement in technology and market forces.

The BIRDS program provides participating members with a unique opportunity to get a hands-on experience on the overall aspects of satellite development. The students get trained in defining missions while enhancing the ability to understand the needs and requirements of stakeholders/users. Throughout the project, each member learn to analyze the situation and make right decision to meet the requirements. The two years of the project involves extensive learning and opportunity to gain key experience valuable for emerging space programs. The team is exposed to first class testing facilities and they are guided by expert faculty members. But above all, the human network established through this program will be invaluable for the future of infant space program of the developing nations.

And as indicated before, the BIRDS program is a crucial foundation laying step, for the students in an effort towards establishing/advancing their own space program. For some nations, the 1U CubeSat built through this project serves as the first satellite of their country. In BIRDS-1, it was first satellite of their nation for Ghana, Mongolia and Bangladesh. And similarly, in BIRDS-2 it will be the first satellite of the country for Bhutan. And also in BIRDS-3, Sri Lanka and Nepal will be building their first satellite of the nation.

Acknowledgement

The BIRDS-2 team would like to express sincere gratitude towards KyuTech for providing such wonderful platform of learning and also to JAXA for providing the launch opportunity and guidance on the development of BIRDS-2 CubeSats.

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References

1. Arifur R. Khan, George Maeda, Hirokazu Masui, JGMNB Project member and Mengu Cho, “Five-nations CubeSat constellation; An inexpensive test case for learning and capacity building,” Proceedings of the 3rd IAA Conference on University Satellite Missions and CubeSat

Workshop & International Workshop on Lean Satellite Standardization Rome, Italy, November, 2015.

2. Stephen Busch, Philip Bangert. Slavi Dombrovski, Klaus Schilling, "UWE-3, In-orbit performance and lessons learned of a modular and flexible satellite bus for future picosatellite formations," Proceedings of the 65th IAC, Toronto, Canada, October, 2014.

3. Taiwo Raphael, Tejumola, BIRDS Project Members, BIRDS Partners, George Maeda, Sangkyun Kim, Hirokazu Masui, Mengu Cho, "Overview of Joint Global Multi-Nation Birds Satellite Project," Proceedings of the 31st ISTS, Matsuyama, Ehime, Japan, June, 2017.

4. Maisun Ibn Monowar, BIRDS Project Team, Mengu Cho, "BIRDS Project: Development and Operation Summary of a CubeSat constellation Project," Proceedings of the 68th IAC, Adelaide, Australia, September, 2017.

5. Apiwat Jirawattanaphol, JGMNB Project Members, JGMNB Partners, Naomi Kurahara, Mengu Cho, "Design and Development of Ground Station Network for CubeSats Constellation, Joint Global Multi-Nation Birds," Proceedings of the 60th Space Science and Technology Conference, Hakodate, Japan, September, 2016.

6. M. Cho, M. Hirokazu, F. Graziani, "Introduction to lean satellite and ISO standard for lean satellite," Proceedings of the 7th International Conference on Recent Advances in Space Technologies (RAST), Istanbul, Turkey, August, 2015.

7. Michael Swartwout, Clay Jayne, "University-Class Spacecraft by the Numbers: Success, Failures, Debris. (But Mostly Success)," Proceedings of the 30th Annual AIAA/USU Conference on Small Satellites, Utah, USA, August, 2016.

8. Yuki Seri, KIT Satellite Project, Hirokazu Masui, Mengu Cho, "Mission Results and Anomaly Investigation of HORYU-II," Proceedings of the 27th Annual AIAA/USU Conference on Small Satellites, Utah, USA, August, 2013.

9. Pauline Faure, Atomu Tanaka, Mengu Cho, HORYU-IV team, "Toward the Improvement of Lean Satellites Reliability Through Testing – The HORYU-IV (AEGIS) Nano-Satellite Case Study," Proceedings of 67th IAC, Guadalajara, Mexico, September, 2016.

10. GEDC Airbus Diversity Award, GEDC Conference in Niagara Falls, Canada, 2017 http://company.airbus.com/careers/Partnerships-and-Competitions/GEDC-Airbus-Diversity-Award.html

11. Kyushu Institute of Technology, Center for Nanosatellite Testing, http://kyutech-cent.net/activity_e.html