Program management for sustainable university CubeSat programs based on the experience of five generations of CubeSat projects, BIRDS program

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ABSTRACT

BIRDS program is a university CubeSat program whose primary mission is capacity building of non-space faring countries. It has been run by Kyushu Institute of Technology, Japan, where a group of foreign and Japanese students designs, builds, tests and operates CubeSats. The program started in 2015. Roughly every year since 2017, BIRDS program delivered and launched multiple CubeSats from International Space Station. In total, the program generated 17 CubeSats in five generations. The satellites have been designed in a way so that even satellite beginners can go through the satellite system life cycles from the mission definition to the operation in two years, the duration of Master course. Subsequent generations of students overlap in the laboratory so that they can inherit the know-hows and the experience directly in-person. The satellite design has been modified based on the lessons learned in the former generations, especially during the operation phase. After going through the series of developments and operations, the satellite bus has become very mature. Currently, the initiative to open-source the BIRDS bus is also running. The program, rather than project, management aspects of university CubeSat program is discussed.

1. INTRODUCTION

It is known that a university CubeSat project fails often, especially if it is the first satellite project of the university[1]. It is also known that the mission success rate improves for the second satellite or later by taking the lessons learned from the earlier failure.

To improve the mission success rate of a university CubeSat, the principal investigator, most of the cases a faculty member or an academic staffhould have a view point as a satellite program rather than individual satellite projects. As a satellite program, the satellite bus and the mission payload are constantly improved by reflecting the lessons learned in the previous projects.

To achieve good results as the satellite program, a careful thought must be given to how to maintain the lessons, knowledge, and knowhow obtained. There is no definite answer, because each case depends on the conditions of individual university, professors, etc. but it is desirable that persons with actual experience of the satellite projects continue to serve in subsequent projects, in addition to recording the lessons in documentation. The program management, rather than the project management, becomes important. The program management tasks are the ones for faculty members or staff, not the ones for students because the tasks are more than building a satellite.

The purpose of the present paper is to introduce the experience of BIRDS program as an example of university CubeSat program management. The BIRDS program is a CubeSat program whose primary mission is capacity building of non-space faring countries. It has been run by Kyushu Institute of Technology (Kyutech), Japan, where a group of foreign and Japanese students designs, builds, tests and operates CubeSats. The first satellite project, BIRDS-1 started in 2015. When BIRDS-1 started, there was no idea of doing a series of satellite projects. But, as BIRDS-2 started in 2016, the viewpoint as a satellite program gradually emerged. Eventually, the BIRDS program delivered multiple CubeSats roughly every year since 2017. In total, the program generated 17 CubeSats in five generations. See Table 1 for the summary.

Table 1: List of BIRDS satellites

Project	Start	Satellite delivery	ISS release	Countries
BIRDS-1	2015.10.1	2017.2.8	2017.7.7	Japan, Ghana, Mongolia, Nigeria, Bangladesh
BIRDS-2	2016.11.7	2018.5.17	2018.8.10	Bhutan, Malaysia, Philippine
BIRDS-3	2017.10.4	2019.2.18	2019.6.17	Japan, Nepal, Sri Lanka
BIRDS-4	2018.10.29	2020.9.25	2021.3.14	Japan, Paraguay, Philippine
BIRDS-5	2020.7.14	2022.6.7	Fall 2022	Japan, Zimbabwe, Uganda

In the present paper, the program, rather than project, management aspects of university CubeSat program will be discussed based on the experience of BIRDS program with emphasis on how to make the program sustainable by solving the many challenges we faced. The paper is made of six parts. The second part describes the overview of the BIRDS program. The third part describes the summary of the flight results and design changes made in each generation. The fourth part describes how the know-hows were maintained and transferred across the generations. The fifth part describes the program missions rather than the satellite project missions. The sixth part gives conclusion and the issues to be solved for a program similar to BIRDS program to be adapted in other universities.

2. BIRDS PROGRAM

BIRDS-1 started as a capacity building satellite project whose aim is to provide hands-on opportunities to students from non-space-faring countries. Kyutech started a long-term fellowship program in collaboration with United Nation Office for Outer Space Affairs (UNOOSA) in 2011. Since 2013, as the fellowship programs expanded under the funding support of Japanese government, Kyutech started Space Engineering International Course (SEIC), which is a post-graduate curriculum on Space Engineering offered in English. As of April 2022, 128 foreign students from 43 countries have enrolled in SEIC forming a diverse student population representing all parts of the world: Asia, Africa,Latin America, and others.

Kyutech built and launched the first satellite, HORYU-2, in 2012. Although the satellite was built as a student project, it was quite successful achieving the full mission success. The second satellite, HORYU-IV, was developed by students enrolled in SEIC. In total, 44 members from 18 countries joined the HORYU-IV project. The satellite was launched in 2016. HORYU-IV was no longer a simple educational satellite. Thanks to the success of HORYU-II, the satellite was funded more than 1.5 million USD by JSPS (Japan Society for Promotion of Sciences). HORYU-IV aimed to generate several research publications based on the results of in-orbit experiments. After all, HORYU-IV was successful by generating 16 peer-reviewed journal papers and five Ph.Ds.

While still working on HORYU-IV, a university president from Ghana (All Nations University) visited Kyutech on May 21, 2015 to discuss an idea of sending students to Kyutech. An idea of making satellites together with students from other countries was born over a dinner that night. The idea of the joint satellite project was proposed to Mongolia, Bangladesh, and Nigeria as those countries happened to be sending three students to Kyutech from October 2015. We formulated a basic scheme of forming a team of total 15 students (including 3 students from Japan), 3 students from each country. To provide a sense of ownership, especially as the country's first satellite, it was decided that each country owns one satellite. It was decided to build five satellites (Japan, Ghana, Mongolia, Nigeria, Bangladesh) in total. After establishing the basic framework of cooperation in four months, the first project, BIRDS-1, kicked-off in October 2015.

The mission statement of BIRDS-1 was "By successfully building and operating the first national satellite, make the foremost step toward indigenous space program at each nation". At this stage, we never imagined to do BIRDS-2 or later. Therefore, BIRDS-1 was considered as another satellite project, whose purpose was primarily education. Because the primary purpose was education, the most important constraint was to do the satellite project in two years including operation.

Since the emergence of small satellites, many non-space-faring countries tried to enter the space sector through small satellite development and operation. Various training programs via agencies, companies and universities in space faring countries existed before BIRDS program. They were often tied with sales of satellites (big or small). But many of them were not successful, especially if the training was done in agencies or companies. The reasons were mainly lack of hands-on experience and not covering the entire satellite system life cycle. Also, in many programs, there was a tragedy of trainees leaving the space organization after returning to their countries because the space program in the non-space-faring countries was not sustainable. The key for successful capacity building program are the following two points,

- Experience the complete cycle of designing, building, testing and operating through hands-on
- Strategy for sustainability after the training

Fitting the satellite project into two years came from these two points.

The short-term goal of the BIRDS-1 was to build and operate a satellite to give the students confidence that they can do it. But the long-term goal was that the students initiate their own space program in their home countries. Therefore, the full mission success criterion of BIRDS-1 was that the former students successfully build and operate the second satellite in their home countries. Therefore, the emphasis was placed on letting students learn the entire process of a satellite project from the beginning to the end. We let the students witness decision-making processes and then make decisions by themselves. By learning what are necessary to build and operate a satellite and what decision they have to make through their own experience, it becomes easy for them to initiate their own space program in home countries even if it starts from a CubeSat project. By starting their own small program by themselves, the program can be more sustainable by not heavily relying on big support from the government. We also asked the stakeholder of each country, mostly university, to make commitment of initiating space education/research program and hiring the BIRDS students as the initial core members.

In order to let the students experience the entire system lifecycle, we have to fit the project within the degree timeline, which is two years for the Master degree program. For Japanese students, we have three years as they usually spend three years in their laboratory, the senior year and two years in Master course. But we had to frame the timeline for foreign students. To fit into two years, we have selected 1U CubeSat and ISS deployment as the platform for this training. 1U CubeSat was chosen obviously as it was the simplest satellite. ISS deployment was chosen as there were routine flight opportunities once every three months in average.

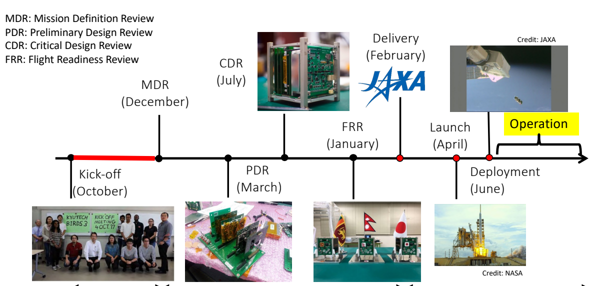

Figure 1: Satellite Project Timeline

The project timeline was laid down as shown in Fig.1. Actual hardware development and testing is only 15 months. Considering the fact that the satellites would be built by beginners, the satellite design was simplified. First of all, as there was no time to develop the satellite bus from scratch in 15 months, the existing satellite bus, HORYU-IV, was adapted. HORYU-IV was not a CubeSat. It had a dimension of 300mmx300mmx300mm weighing 10kg approximately. The circuit diagrams of OBC (Onboard Computer), EPS (Electrical Power System), and COM (Communication) were shrunk to 2 PCBs of 90mmx90mm with the help of a professional company specialized in electronics circuit board design and manufacturing. Figures of the PCBs are shown in Fig.2.

Regarding the UHF/VHF communication, the same transceiver as HORYU-IV was selected for BIRDS-1.

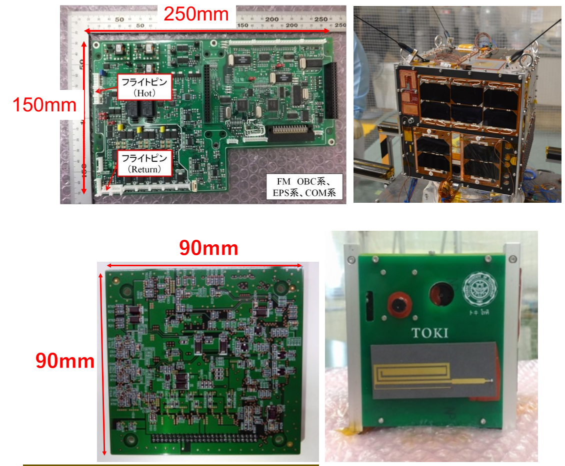

Figure 2: HORYU-IV OBC&EPS (top) and BIRDS-1 OBC&EPS (bottom)

In addition to inheriting the design of previous satellite projects, the satellite was designed for easy assembly and disassembly by adapting the backplane architecture as shown in Fig. 3 proposed by University of Wurzburg[2]. We tried to reduce the harness as much as possible. Also, each satellite in the same generation has exactly the same design and uses the same frequency (UHF/VHF amateur radio) to avoid any mistakes during the final assembly, integration and testing phase. Each satellite is distinguished by a physical mark on the antenna plate and uses a different call-sign.

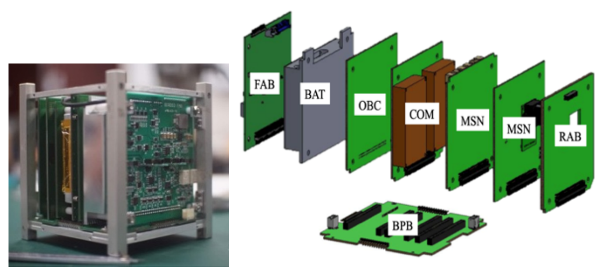

Figure 3: Backplane architecture

The BIRDS program experiments the lean satellite approach. Lean satellites seek to deliver value to the customer (the end-user or the purchaser) or the stakeholder at minimum cost and in the shortest possible schedule by minimizing waste [3]. We try to achieve the maximum reliability within the budget and schedule constraints. To do so, we evaluate, prioritize and mitigate risks properly to fit into the small budget and short schedule. When the students continue the space program in their home country, they have to adopt a lean approach anyway so that the program can run with a small team and at minimum cost.

In the BIRDS program, the overall satellite development activities occur within a radius of 30 m of a central spot on campus. All the team members are placed in one room where they spend most of the time while they are on campus. The clean room is located next to their room and the testing facility is located downstairs. Operations are done in the building next door. To minimize the waste of waiting for a reply, the students are encouraged not to use e-mail unless they need to broadcast a message to all the team members.

Figure 4: Student office and work room

3. FLIGHT RESULTS AND DESIGN CHANGES

Fig. 5 shows the evolution of BIRDS satellites. At each generation, we had to give changes to the satellite bus. They are summarized in Table 2.

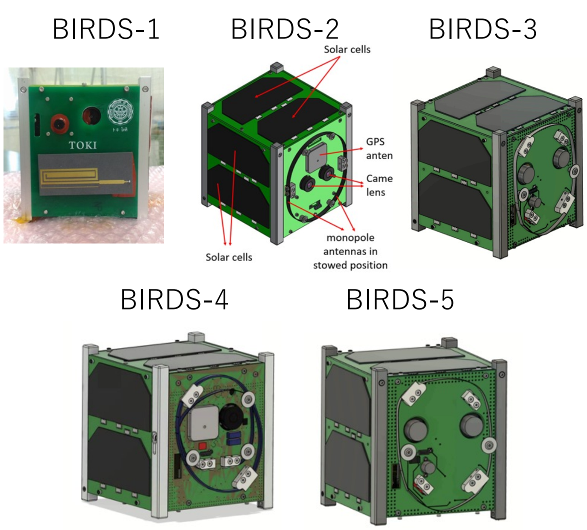

Figure 5: Evolution of BIRDS satellite

Table 2: Summary of design changes in BIRDS program

Project	Flight results	Design change
BIRDS-1	No uplink success Weak CW signals	
BIRDS-2	Strong CW Very few uplink success APRS beacon OK, but no uplink	Deployable antenna UHF uplink
BIRDS-3	Full mission success	Dipole antenna New OBC/EPS
BIRDS-4	Full mission success Loss of two satellites due to power shortage	3xDeployment switch
BIRDS-5		No rail switch

The changes from BIRDS-1 to BIRDS-2 were dictated by the communication problem encountered in BIRDS-1 and also by changes in some IARU rules. BIRDS-1 carried experimental patch antenna for both UHF (downlink) and VHF (uplink). The gain of the patch antenna was not as good as expected. The problem was not detected by the ground tests because the flight model antenna arrived at the last minute and no system communication tests were done with the flight models. Moreover, it was the mistake of project management to use the patch antenna for all the five satellites. As the patch antenna was not proven technology, it should have been tested as a mission payload, not used for the satellite bus. BIRDS-2 started with the same patch antenna. But as we found the patch antenna not working well in orbit, we switched to more conventional deployable antenna. That time BIRDS-2 project was about to enter the flight model stage. It took additional three months due to the design change. It is an example of swiftly implementing "lessons learnt" from one generation to the next. Also, from BIRDS-2, the uplink frequency changed to UHF as IARU no longer allocated uplink VHF frequency. The regulation change affected the design.

Thanks to the deployable antenna, BIRDS-2 had a much stronger beacon signal. Although the downlink signal strength was improved drastically, the uplink suffered difficulty. The reason was the internal noise generated by EPS board. In a CubeSat, all the electronics systems are packed in a tiny volume, creating many paths of noise coupling. For downlink, this is not an issue. But for uplink, the signal at the satellite is very faint due to the free path loss and susceptible to the noise. For a bigger satellite, there can be several ways of noise decoupling. But for a CubeSat it is very difficult. We could have detected this problem during the ground test. The reason we could not detect was that we overlooked an internal attenuator of 10dB in the reference diploe antenna used in the test. Therefore, the link budget was overestimated by 10dB. The root cause was the project management issue. Only a few members were familiar with the communication test. Therefore, the test procedure and the results were not examined in detail. The noise issue affected both the UHF uplink for the command and the VHF uplink for the APRS mission. After improving the ground station, we finally succeeded in the UHF uplink after 1 year from the satellite deployment.

The BIRDS-3 project saw the noise issue of BIRDS-2 while the team was working on the engineering model. The antenna design was modified to diploe antenna and more ground plane was allocated in the antenna panel. The shielding of the transceiver and the EPS board was done. The polarization was changed from linear to circular. The ground station antenna was improved. Thanks to these, BIRDS-3 had no issue of communication. The details of how we managed the communication problems can be found in Ref.[4].

When we started BIRDS-3, we faced the situation that the microcontroller used for OBC, Renesas H8, was discontinued by the manufacturer. Considering the sustainability for future, the design of OBC and EPS has been renewed extensively. The major points were to select PIC micro-controller and modify the power circuit to adopt to the change in cold-launch requirements. Also, we separated the satellite bus from the mission payloads, so that even if the mission payload changes, we can still use the same satellite bus. Figure 6 shows the OBC/EPS and FAB boards used for BIRDS-3. Figure 7 shows the BIRDS bus as a CubeSat platform. There are two slots on the backplane where a PCB carrying mission payload can be inserted. Basically, this design has been used until BIRDS-5 with minor modification. Three satellites of BIRDS-3 worked in orbit for nearly two years and achieved the full mission success.

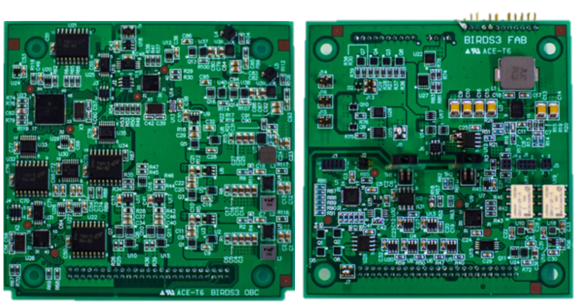

Figure 6: BIRDS-3 OBC/EPS (left) and FAB (right)

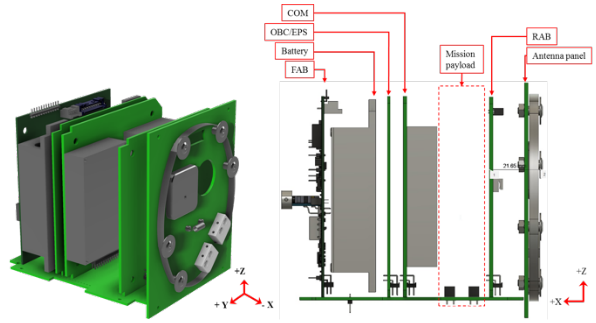

Figure 7: BIRDS bus as a CubeSat platform

When we started BIRDS-4, JAXA changed the interface of the satellite deploy case. The satellite cannot use the RBF (Remove-Before-Flight) pin for safety. FAB was modified to adapt one more switch which was placed at one of the side rails. Besides this, BIRDS-4 concentrated in doing more satellite missions. The satellites carried various missions, such as Earth imaging, APRS, body mounted antenna, perovskite solar cell, solar cell glue, attitude control, etc. Students were busy making the mission payloads. BIRDS-4 took additional 6 months to deliver the satellite compared to earlier generations. The cause was the delay in the frequency coordination, which occurred due to miss-communication between the team and the radio authority. Fortunately, all the members except one Japanese student did not graduate before the satellite deployment from ISS. See Ref.[6] for the satellite missions of BIRDS-4.

In one week after the deployment from ISS, we lost two satellites. The cause was the loss of solar panel and inadequate power management. Solar panels of BIRDS satellites are built by students. We buy space-grade solar cells from Azur. But lay-down of the solar cells to the panels is done by students. The solar cells are attached with RTV silicon glue and conductive adhesive. The N-electrodes are soldered to the PCB pattern on the panel, instead of being welded to the P-electrode. This strategy was chosen because the students should be able to manufacture the panels in their home country without relying on expensive tools. We observed two solar panels failed in BIRDS-3 but the satellite functioned with the loss of one panel per satellite. This fact pushed us into having over-confidence in the power budget.

Two BIRDS-4 satellites had failure in one solar panel soon after the deployment. The power budget was in deficit and the battery power kept decreasing. The difference from BIRDS-3 was that BIRDS-4 consumed more power in the nominal mode, mainly for battery heater and attitude determination. The problem could have been detected by careful design review. The root cause was the lack of oversight by faculty members. Because BIRDS-3 had no issue in orbit, the faculty members paid little attention to BIRDS-4 satellite development. The power deficit was realized only after looking at the flight telemetry data. This experience gave a lesson that even if the satellite bus design is solid, a careful oversight by senior staff is necessary if the satellite is made by beginners.

BIRDS-5 started in the middle of pandemic. The satellite meetings were done remotely. Although the time to stay in the office and working room was limited and controlled, fortunately, the students could still come to the campus to work on the satellite. The satellite bus design suffered the change of the deployer case interface by JAXA again. This time, rail switch was not recommended. Therefore, we moved the third switch to the end of a side rail, which resulted in the design change of the structure. Although we are making satellites every year, every time we had to change the design due to external causes, such as IARU policy, parts supply, launcher interface, etc. It is difficult to maintain the same design even for several years.

The lessons learned in BIRDS-4 were implemented to BIRDS-5. First of all, faculty members tried to oversee the satellite activities more to give advices to the students who are all the beginners of satellite making. The power budget was strictly monitored. During the full system functional tests, it was constantly pointed out to monitor the consistency of the telemetry data to find any anomaly in the data. In terms of satellite design, the backplane uses CPLD (complex programmable logic device) to adapt to various mission payload design by software change. One satellite of BIRDS-3 carried CPLD as a mission and demonstrated its sound functionality in orbit for nearly two years [6].

4. KNOWLEDGE TRANSFER AND MAINTENANCE

As mentioned above, the satellite designs evolved constantly by reflecting the flight results and adapting the changes imposed by external causes. The design changes could be implemented rapidly as there were always overlaps of student generations. In 2018, when we started BIRDS-4, all the BIRDS-3 members were still at the school. We still had a majority of BIRDS-2 members and even three BIRDS-1 members. A group photo taken at the kick-off of BIRDS-4 is shown in Fig.8. In the figure, the three students in the top rows are students who worked on BIRDS-1. They were still at the schools as they moved to Ph.D. course after the Master degree.

Since BIRDS-2, it became tradition that the students of the former generations tutor the new students in person. When there is a question in the satellite design, the student can go quickly to the senior students. By creating this system, the burden on the faculty members is relieved significantly, although relying too much on the intra-student tutoring led to the loss of the two BIRDS-4 satellites.

Figure 8: Group photo taken in Fall 2018.

Knowledge transfer and maintenance is always an issue in university satellite programs. One obvious solution is to prepare documents. But it is very rare to find a student who likes writing documents. It is good to have persons who experienced the satellite projects by themselves. In university satellite programs, students graduate. Therefore, the persons must be either faculty members or academic staff. For the staff, we have to consider how to secure the continuous funding for employment, the school regulation related to the term of employment, the academic carrier of the staff, etc. For the faculty members, they have to commit themselves as a program director and spend a significant amount of time in each satellite project, which may affect the academic career of the faculty members especially if the person's rank is still at a junior level before obtaining tenure.

In BIRDS program, we took a strategy of maintaining the knowledge and experience as "collective intelligence" among the students by overlapping several generations of satellite projects concurrently. The senior students teach the junior students the experience based on the operation results. This strategy requires the funding to support the multiple satellite projects. The principal faculty must work really hard to get the funding. Also, without supporting academic staff, such post-doc or junior faculties, between the principal faculty and the students, the burden on the principal faculty is too heavy. The support by the junior staff is critical. In turn, the principal faculty must think about the academic career of the junior staff. Also, once the technology is fully matured after experiencing a number of orbital operations, an approach whereby the results of the projects are returned to society is desired by transferring the design and knowhow to enterprise, such as by making them available as opensource.

5. BIRDS PROGRAM MISSIONS

BIRDS-1 started as a one-shot satellite project. But as we carried out later satellite generations, the nature of the satellite program evolved. Now we can see the BIRDS satellite projects as a program rather than a series of projects. Then the mission of BIRDS-1, "By successfully building and operating the first national satellite, make the foremost step toward indigenous space program at each nation" is not enough to express the overall missions of the BIRDS program. Currently, the program missions can be summarized into the following four points,

1. Support capacity building efforts of non-space faring countries
2. Make satellite building easier
3. Develop human resource through international joint satellite projects
4. Learn systems engineering and project management through satellite development and operation

The first and second items aim at **<u>lowering the entry barrier to the space sector</u>**, not only for non-space-faring countries, but also for others such as companies, universities, and other organizations. The third and fourth items aim at **<u>practicing a new engineering education</u>** with Japanese students as a major target (especially the third item).

Under these program missions, the BIRDS program is now made of the following projects,

1. Satellite projects
2. BIRDS network project
3. Open-Source project
4. Standardization project

The second item, BIRDS network project, is carried out with BIRDS partners who were mainly the former BIRDS stakeholders. The BIRDS network is made of two networks. One is human network formed during intensive two years project by "living under the same roof". The network is expected to assist infant space programs each other in surviving "hard times" and other difficulties. The other is ground station network, which is the physical backbone of the network. Each BIRDS partner commits to build a ground station when they join the satellite project and participate in the satellite operation. Having a ground station in each country, future joint satellite projects become easier to implement.To maintain the BIRDS network, we have been conducting two in-person international workshops every year since 2016. One is BIRDS workshop where senior people from each member join to discuss strategic issues. Another is BIRDS GS workshop where young people gather to do hands-on activities on satellite operation. Due to the pandemic, the BIRDS network activity was limited to remote meetings. But we will soon start in-person meetings.

The third item, open-source project is currently carried out actively by involving not only BIRDS partners but those who were outside the BIRDS network. The idea of open-sourcing the BIRDS bus started in 2020. Using the idle time during the pandemic, we were having a monthly meeting with the former SEIC students. Many former students reported difficulty of promoting the domestic satellite projects in their countries. The full mission success criterion of BIRDS program is that the second satellites are built domestically by former BIRDS students. We found that the easiest solution for the second satellites was to duplicate or modify BIRDS satellites which they were very familiar with. But Kyutech is not a company and cannot maintain the satellite bus. Also, if a company commercializes the BIRDS bus, it will be expensive as the company needs to get a profit. The most affordable way is to let users work on the satellite by themselves. Also, we considered making others (non-BIRDS members) benefit from the initiative. Then the conclusion was to open-source all the technical information related to the BIRDS bus.

We have decided to put basically all the technical information related to the satellite design, which includes the following,

- Technical Drawing (i.e., CAD files)
- Source code (satellite and ground station)
- PCB design
- Assembly and testing procedure
- Parts list
- Test reports
- Interface Control Documents
- Textbook

As of June 2022, information about BIRDS-3 and 4 are available at GitHub[7]. By summer of 2022, information about BIRDS-5 will be posted at GitHub as well as the in-orbit results (temperatures, voltage, current, etc) of BIRDS-3 and 4. Another source of information can be found in "BIRDS Project Newsletter" which is a large documentation package of the BIRDS program (75 monthly issues). The archive can be accessed freely at Ref.[8]

In an open-sourcing activity, it is important to define the licensing policy. In BIRDS bus open-source, we have decided to adopt the so-called "MIT license", which is the most flexible licensing option giving users wide freedom as long as they acknowledge the origin of the information ask the others to do so.

As of June 2022, there are five Japanese users who are using the BIRDS bus for their satellite projects. Internationally, there are four countries, all from the former BIRDS countries, using the BIRDS bus. This became possible because the BIRDS bus was designed so that it can serve as a CubeSat platform accommodating various mission payloads while having the minimum change in the satellite bus design. The information is open to anybody including non-BIRDS countries. All the information related to the open-source initiative is distributed at a portal site at [9].

6. CONCLUSION

BIRDS-1 satellite project started in 2015 as an educational satellite project for the capacity building purpose. As the series of satellite project continues, starting a new project every year, what was merely a one-shot satellite project became a satellite program in which the satellite design was improved continuously reflecting the lessons learned in the satellite operation.

Approach of using "collective intelligence" among the students by overlapping generations of the satellite project and promoting direct know-how transfer among the students, lessened the burden on the principal faculty. But at the same time, this approach proved to force the principal faculty seeking continuous funding to run the multiple satellite projects simultaneously.

After going through the series of developments and operations, the satellite bus has become very mature. Thanks to its design differentiating the mission payloads and the satellite bus, the BIRDS bus evolved as a good platform to be used for academic satellite projects. Currently, the initiative to open-source the BIRDS bus is also running and nearly 10 users are using the satellite bus worldwide.

We can say that the BIRDS program is an example of a sustainable university satellite program that ran for more than 8 years since its inception. The key to be sustainable were the two points. One was the success in securing the funding. This required dedicated persons for the international liaison and the international contract, both very rare in Japanese universities. The other was the presence of junior staff between the professor and the students, who really took care of the satellite project and serves as the knowledge database that could not be inherited among the students.

To adapt a program similar to BIRDS program, launching a satellite project every year so that the student generation overlaps each other, the key is the funding including the employment of junior staff dedicated in overseeing the daily project. To lower the funding barrier, lowering the satellite hardware cost and the launch cost are necessary. As of now, BIRDS satellite bus costs 4MJPY, equivalent to 40KUSD, per unit. Two items, UHF transceiver and solar cell glue (RTV S-691) are the cost drivers. Efforts to lower those costs are necessary and the outcome should be shared in the opensource activity.

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