Development of 2U CubeSat "YOTSUBA-KUlover" for Geomagnetic Field Measurement by Undergraduate Student Satellite Project

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ABSTRACT

Kyushu Institute of Technology(Kyutech) have developing small satellites since 2006. Three satellites, AOBA-Velox III, FUTABA and MITSUBA(Unfortunately, lost due to rocket launch failure) have been developed in a student satellite project. This satellite project is promoted by under graduate students. The students conduct all of satellite development process as design, integration, test, safety document preparation and operation. Students can learn the satellite development process through hands-on. Fourth satellite is 2U Cube satellite for measurement of geomagnetic field "YOTSUBA-KUlover" and this program is a joint program with Kyushu University. It is the first satellite developed by Kyutech students project to conduct a science oriented mission. The International Space and Planetary Environment Science Center (i-SPES) at Kyushu University has been conducting international observations of the geomagnetic field for many years, and the center support the development of magnetic field sensor. Kyutech students developed bus system based on the past satellite heritage and Kyushu University students developed a mission component for geomagnetic field measurement and camera for aurora measurement. The main mission of the YOTSUBA-KUlover is a precise measurement of geomagnetic field with an accuracy of 0.1 nT to observe the magnetic perturbations related to the magnetic storms and/or aurora substorms. To achieve this accuracy, a deployable boom was developed to reduce the effect of satellite residual magnetic field. In addition, the effect of the operation of each bus component on the magnetic sensor was investigated in a magnetic calibration facility in Kyushu University. YOTSUBA-KUlover will be launched in FY2024 and currently flight model is being developing. The presentation will introduce the specifications of the satellite and discuss the progress of the development and the problems specific to student satellite projects.

INTRODUCTION

Kyushu Institute of Technology (Kyutech) has been developing microsatellite and CubeSat since 2006. Total 29 satellites were launched so far. The satellites were developed for various purpose as technology demonstration and capacity building. A one of activity for the capacity building is the satellite development by "Kyutech Satellite Development Project" mainly managing by bachelor students. A similar capacity building program, the Birds Project, is also in operation for international students[1-3]. This project is not conducted as a lecture but as an extracurricular activity for students. The purpose of the student satellite project is to learn space engineering practically. Through design, development, testing, and safety review, students learn the actual process of manufacturing, which cannot be learned in a typical lecture. Three satellites of AOBA-Velox III[4], FUTABA[5] and MITSUBA[6] (this satellite was lost because of rocket failure[7]) have been developed. Table 1 shows the review of the satellites by the student project. The satellite bus system has been developed continuously over a long period of time. The reason why we continue to develop satellites by students is that the learning effect is very high, and the degree of growth of students before and after the project is significant. Fourth satellite of "YOTSUBA-KUlover" is under development. It is a the first satellite by the student project dedicated to a purely scientific mission, not a technology demonstration. This paper present the development of YOTSUBA-KUlover and lessons learned from the satellite project by students.

Table 1 Review of Past Satellite Project

AOBA-Velox III	Size : 2U
	ISS deploy
	Period of activity : 2014 to 2016
	On-orbit demonstration of PPT
FUTABA	Size : 1U
	ISS deploy
	Period of activity : 2017 to 2022
	Observation of whisker growth on-orbit
MITSUBA	Size : 2U
	Rocket launch with Eplison
	Period of activity : 2020 to 2022
	Measurement of degradation of COTS part due to radiation effect

SATELLITE SPCIFICATION AND ARCHITECTURE

Figure 1 shows the appearance of YOTSUBA-KUlover (FM). Table 2 shows the specification of the satellite. The main mission of YOTSUBA-KUlover is the precise measurement of geomagnetic field with a fluxgate magnetometer. This satellite project is joint program with Kyushu University. Especially, International Research Center for Space and Planetary Environmental Science (i-SPES) in Kyushu University has a lot of experience in ground-based geomagnetic observations. An undergraduate student from Kyushu University developed the magnetic sensor. The satellite is deployed from ISS. This is a paid launch service with a more flexible launch schedule than regular rocket launches.

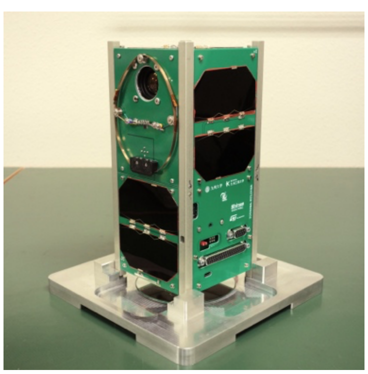

Figure 1 : YOTSUBA-KUlover Flight Model

We selected a none-armature frequency. For this satellite, the non-amateur frequency band was selected, whereas previous satellites have used the amateur frequency band. This is because the purpose of the satellite's mission is outside the guidelines for the use of amateur frequencies and amateur frequencies are harder to obtain than in the past. However, the transceiver provided from Nishi Musen Crop. is the same as that used in previous satellites, with a few modifications.

Table 2 Specifications of YOTSUBA-KUlover

Size	100 x 100 x 227 mm (2U)
Weight	2.66 kg (Max)
Launch method	Deploy from ISS
Altitude	Release from about 420 km
Inclination	51.6 ˚
Communication	Uplink : 450 MHz,
	Downlink : 401 MHz
Mission	Main : Measurement of geomagnetic field Sub : Aurora photo taking

Figure 2 shows the satellite architecture. Kyutech provided the satellite bus system based on MITSUBA. This bus system has been improved for each project and established as a stable system. The bus system by Kyutech side is “YOTSUBA” and the mission part by Kyushu University is “KUlover”. CW-PIC can reset MAIN-PIC, COM-PIC and MISSION PIC. This reset system was implemented to prevent latch-up due to radiation. A Raspberry Pi was used for controlling of camera. This camera was installed to take a photo of Aurora.

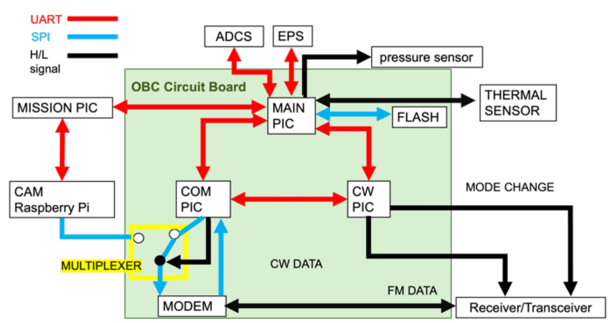

Figure 2 : Architecture of satellite

Figure 3 shows the communication architecture. Main-PIC processes a telemetry data and housekeeping data. CW-PIC receives the telemetry data from Main-PIC and processes morse signals. PIC16LF877A used in CW-PIC is a very old processor, so it is highly resistant to radiation, especially single events. Even if other processors fail, the highly reliable CW-PIC can reset other processors to ensure system stability. In addition, The stable operation of the CW-PIC allows the satellite to be tracked in any situation because the Morse signal is always transmitted.

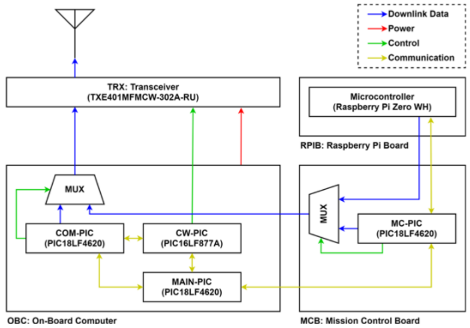

Figure 3 : Architecture of communication

A big design changing from MITSUBA was installing of a deployment paddle of the magnetic sensor as shown in Fig. 4. In a precise measurement of the geomagnetic field, the residual magnetic field of the satellite should be suppressed because the components as BAT, EPS and COM have a strong magnetic field. To reduce the effect of the residual magnetic field, the magnetic sensor should be located to the outside of the satellite structure. However, because of the stringent envelope requirements[8)] imposed on CubeSat, it is necessary to deploy the sensor after it is released from the POD in orbit.

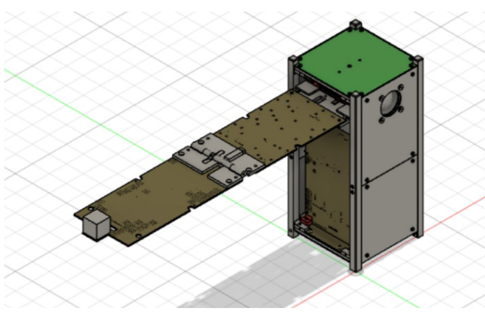

Figure 4 : Deployable paddle for magnetic sensor

ENVIRONMENTAL TESTING

Vibration test

Kyutech have a testing facility "Center for Nano Satellite" (CeNT)[8)] for the satellite less than 50 kg. For the most of environmental tests for YOTSUBA-KUlover, the machines in CeNT were used. The availability of environmental testing facilities is one of the strengths of this project, and low costs will be realized because there are no equipment rental fees or travel expenses required for environmental testing.To assure the satellite structure strength and requirement for natural frequency, a vibration test was conducted. Figure 5 shows the test setup. The satellite was installed to the test POD and three accelerometers were attached to the satellite body to measure the natural frequency.

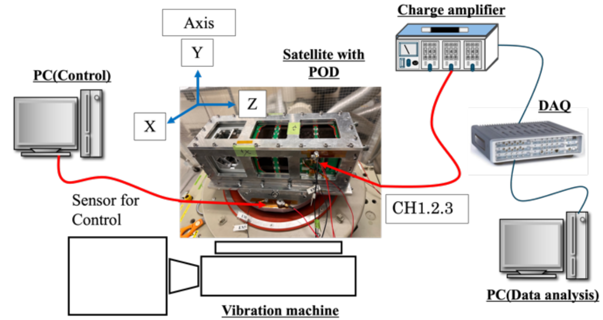

Figure 5 : Test Setup of vibration test

Table 2 shows test conditions. The launch vehicle to be used for the actual launch was not yet determined at the time the vibration test was conducted. Therefore, levels were used that would accommodate the vibration conditions of all rockets that might be used for launch.

Table 2 Condition of Random vibration

Frequency, Hz	PSD, G^2/Hz
20	0.0250
30	0.0250
36.1	0.0181
80	0.0400
500	0.0400
2000	0.0100
G_{rms}	6.8
Sec	60

Figure 6 shows the measured natural frequency. Red and black are before and after test respectively. The change in natural frequency before and after the test was within -3.0% at maximum, and no structural changes occurred. In addition, no cracks on the solar cells and loosing bolts were found from a visual inspection after the test.

Thermal Vacuum Test (TVT)

Thermal analysis has not been actively carried out because our many satellites have already been launched and temperature data has been collected, making it possible to predict temperatures. From corrected on-orbit data, the expected temperature range of CubeSat without an active attitude control are -25˚C to +40˚C. However, the actual temperature range in the TVT was set to from -25 ˚C to +60 ˚C because the temperature range expected from on-orbit data does not include margins and this condition is too small to evaluate components. In the thermal vacuum test, the temperature of external panels were adjusted to -20 ˚C to +60 ˚C range. Figure 7 shows the temperature profile in the TVT.

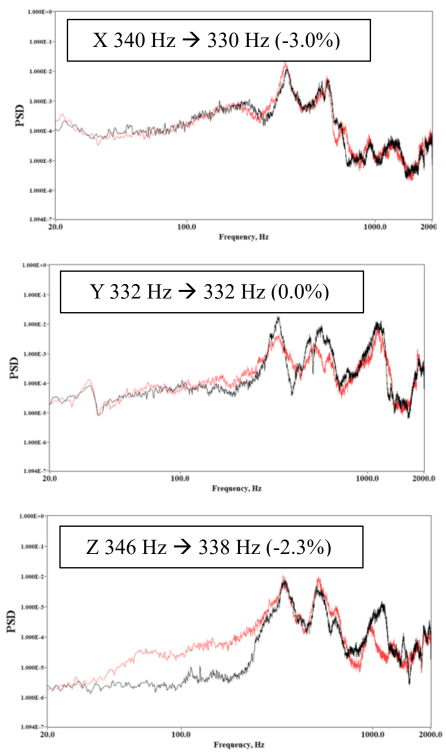

Figure 6 : Measured natural frequency

(Top X, Middel Y, Bottom Z)

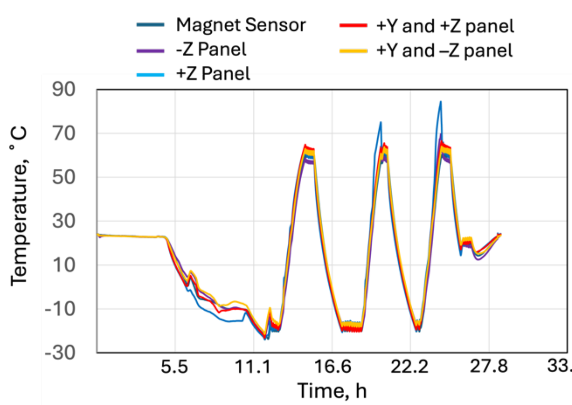

Figure 7 : Temperature profile in TVT.

During the TVT, the satellite operated as a nominal operation in the on-orbit and the function was checked. The basic function of the satellite was verified in the temperature range.

Communication test and link budget

To check the performance regarding to the communication system, several tests were conducted in an anechoic chamber. YOTSUBA-KUlover equips deployable dipole antenna. Before the communication test, the antenna impedance was optimized by using a vector network analyzer. The first test is antenna pattern measurement. Figure 8 shows the test setup in anechoic chamber. The satellite located on the rotation table. The pattern of radio wave emitted from the antenna was measured by gradually changing the satellite's position. The patten for horizontal and vertical axis was measured. Figure 9 shows the measurement results.

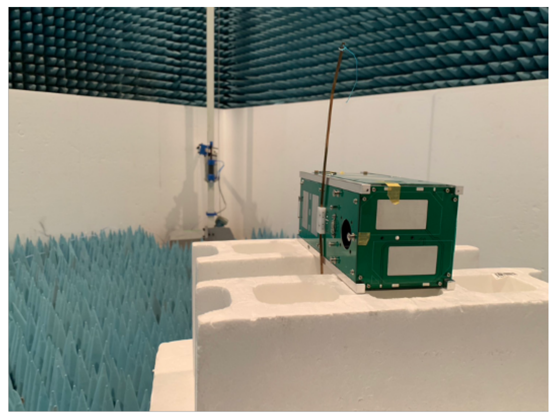

Figure 8 : Communication test in anechoic chamber

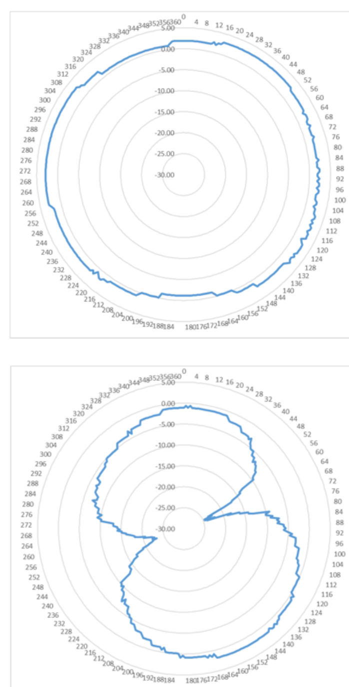

Figure 9 : Antenna pattern measured for 401 MHz downlink (Top : Horizontal, Bottom : Vertical)

From the test results in the anechoic chamber, the antenna patten is almost same as a typical radiation pattern of bipolar antenna for horizontal and vertical axis of antenna. Finally, the link budget was recalculated by using the latest value based on the test. The budget link of downlink and uplink are shown in Table 3. Positive communication margins for both up and down were confirmed based on actual measurement parameters.

Table 3 Budget link for downlink (top) and uplink(bottom)

Downlink	Beacon, CW
Receive antenna gain, dBi	19
Required S/N ratio, dB	10
Noise Temperature, K	300
Noise Floor, dBm	-147
Received Power, dBm	-130
Required received power, dBm	-137
Link margin, dB	**6.9**

Uplink	Beacon, CW
Receive antenna gain, dBi	19
Required S/N ratio, dB	12.6
Noise Temperature, K	300
Noise Floor, dBm	-135
Received Power, dBm	-117
Required received power, dBm	-122
Link margin, dB	**5.5**

Magnetic Sensor Calibration

An important test for YOTSUBA-KUlover is a calibration of magnetic sensor. The sensor was mounted on a deployable panel to eliminate the effects of the satellite's residual magnetic field, but the extent of the effect was not evaluated. However, it is difficult to measure the geomagnetic field accurately in a place like a normal laboratory because of the large influence of magnetic field from electrical devices. We brought the satellite to a magnetic calibration facility owned by Kyushu University and calibrated the precise magnetic sensor. The facility is located as far away from the center of town as possible to eliminate the influence of external magnetic fields. At the same time, we checked the generated magnetic field from the satellite during nominal operation. Figure 10 shows the setup of the test. The paddle attached the magnetic sensor was actually deployed and its value was reviewed. Figure 11 shows the magnetic field value measured by the sensor during satellite operation. In this graph, the times of high magnetic field strength coincided with the times when the COM was operating. It was found that COM operating have a strong effect to the geomagnetic field measurement. Regarding magnetic data acquisition, we addressed this issue by changing the sampling timing so that data would not be acquired while the COM was operating.

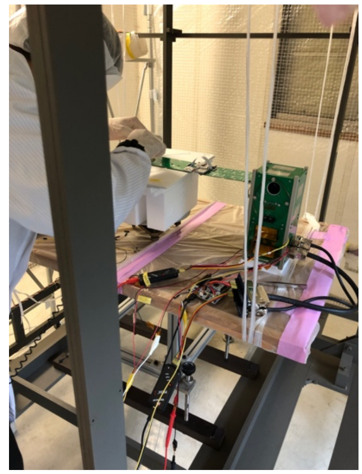

Figure 10 : Test setup of sensor calibration.

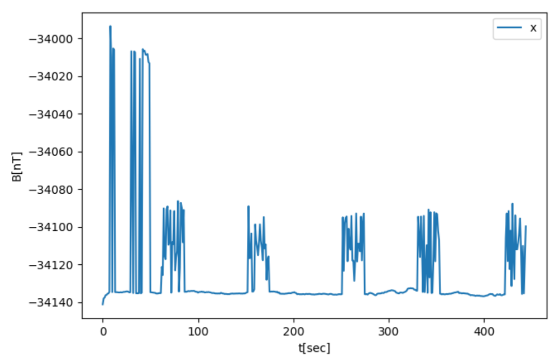

Figure 11 : Measured magnetic field changing during satellite operation

LESSONS LEARNED ON STUDENT PROJECT

Here we will change our perspective and introduce some of the issues specific to student projects that are not engineering related.

The same mistakes are repeated even after explanations

Faculty mem want to establish a stable bus system and specialize in the development of mission equipment, but students inevitably try to build a system from scratch. They do not respect past assets. Therefore, they always repeat the same mistakes. As a result, time is wasted on troubleshooting and the bus system does not become established. Even if this is explained in advance, it is a new experience for the students, so the explanation from the faculty staff is not taken seriously. From the staff's point of view, it seems like the students are repeating the same thing every time.

There is no way to restrain students

Because it is a student project, it is less restrictive. There is no need for credits or salaries. Therefore, if students find other things that interest them or lose interest in the satellite project, they can leave the project. If a student who plays an important role in a subsystem leaves, the development will not be able to continue.

Active working time is short

First year-students have time but lack the skills. In second and third years students, their skills improve, but the number of lectures increases and the time they have to work on projects decreases. In their fourth-year students, they are assigned to a research lab and their time is taken up by research and job hunting. It is necessary to plan their education from the first year and set a schedule that allows them to work smoothly on satellite development.

Fewer free launch slots and rising launch costs

Previously, Japanese universities were able to use the H2A rocket's free slots and the low-cost ISS deployment, but in recent years, fees have been increasing. This student project is funded by a fund made up of donations from alumni and crowdfunding, but it is extremely difficult to cover launch costs from these budgets.

CONCLUSIONS

Kyutech and Kyushu University students satellite project are developing fourth satellite "YOTSUBA-KUlover". Kyutech developed the bus system side based on past satellites developed in Kyutech. Kyushu University developed the sensor for geomagnetic field measurement and the camera for Aurora image taking. By using the machines in Kyutech facility, environmental test was carried out. Through several environmental tests, the satellite function and validation was verified. The magnetic sensor calibration was conducted in the magnetically shielded facility. From this test, it was found that the communication generated a strong magnetic field during operation. YOTSUBA-KUlover will be launched in FY2024.

Acknowledgments

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