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Development of Nano-Satellite Cute-1.7+APD and Its Current Status

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Abstract Laboratory for Space Systems, Tokyo Tokyo Institute of Technology group undertake student leading development of small-satellite. In 2003, Our first satellite, cubesat "CUTE-I", was successfully launched. And now, second satellite named "Cute-1.7+APD" is under development. Cute-1.7+APD has a size of 20cm x 10cm x 10cm, and weight 2kg class, just as double scale as CUTE-I. In Cute-1.7+APD project , we aim for 1) demonstrating a new methodology to facilitate future micro-satellite development and 2) sharing experiment opportunities using satellite in orbit. To realize these , Cute-1.7+APD has various engineering missions such as PDA (Personal Digital Assistant) controlled operation, attitude control experiment using magnet torquers, tether deployment experiment, 1.2GHz amateur band uplink and so on. In particular, as a science observation mission, a high energy particle sensor using APD (Avalanched Photo Diode) is planned to be demonstrated. Cute 1.7+APD is scheduled to be launched in February 2006 with a Japanese solid-rocket M-V#8. This paper explains an overview of the missions and development status of these projects.

Key words nano-satellite, cubesat, student development, PDA, APD, M-V rocket, launch

1. Introduction

Tokyo Institute of Technology (Tokyo Tech), Laboratory for Space Systems (LSS) had developed a 1 kg pico-satellite cubesat, "CUTE-I" (Fig.1), and it was successfully launched on June 2003. CUTE-I still keeps steam and strongly transmits its house keeping data to the Earth. This is an unexpected great success, and which gives us an acquisition of satellite bus technology[1-3]. At the same time, we have demonstrated student leading satellite development, launch and operation. Based on these technology and know-how, we move on to the next satellite development project "Cute-1.7+APD" pursuing new possibility of small satellite.

Cute-1.7+APD project has two goals. The first one is to facilitate future microsatellite development by demonstrating a new design methodology. To realize it, we should consider use of high performance and low cost commercial devices in space. Cute-1.7+APD has several COTS devices such as PDA (Personal Digital Assistant), and radio transceivers.

The second goal of the project is to share experiment opportunities using real satellite with space engineering researchers, students, and other enthusiast. Cute-1.7+APD is equipped with three magnetic torquers and has program upload functionality in order to enable on-orbit experiment about advanced control algorithm.

In this paper, firstly, outlines of Cute-1.7+APD missions and systems are introduced. Secondly, we refer to disclosure of acquired data. Thirdly, current status and future plan are described. Finally, we show conclusions.

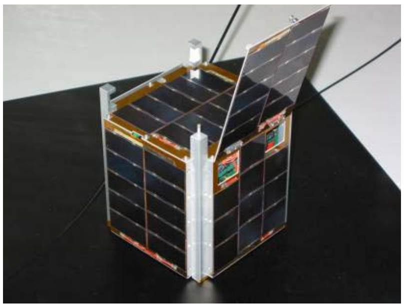


Fig.1 Tokyo Tech Cubesat "CUTE-I"

2. Mission Overview

Main missions of Cute-1.7 are followings.

1) Demonstration of PDA as an onboard computer
2) Attitude control experiment using magnetic torquer
3) Amateur radio service – digital repeater
4) Tether deployment experiment
5) Demonstration of APD sensor

2.1 PDA Based OBC

Use of commercial-off-the-shelf devices is accelerated in space applications. Our previous CubeSat, CUTE-I, was composed of all commercial grade parts. Especially, its FM transmitter and receiver, which are commercial handheld transceiver, have functioned without any error for more than two years. Having this experience and having the objective to facilitate satellite development, in Cute-1.7 project, we are trying to be at the extreme end in terms of use of commercial products in a satellite. Cute-1.7 will depend on commercial finished products rather than only on commercial grade electric parts.

Main computer of Cute-1.7 is Personal Digital Assistant (PDA) in Fig.2, size of which is about 100mm × 70mm. PDA's operating system is Windows CE.NET 4.1 and primary communication line is USB, making the system friendly to potential satellite users. For long-term memory, SD-card is inserted. To make up a redundant system , two PDA are used with a switch device. If one PDA comes to be reset or doesn't works well, the other boots up.

Of course, enough evaluation is required to make the total system reasonably reliable. To ensure that PDAs can function in space, a radiation protection circuitry was developed, and radiation test (proton beam) at RCNP, Osaka University was conducted. Test results showed that PDAs have low probability of SEU or SEL[4]. In 800km circular orbit, SEU would occur once every two years. Probabilities are low enough for Cute-1.7 to function correctly for about a year.

external view(left), internal circuit board(right)

Fig.2 Hitachi PDA NPD-20JWL

2.2 Attitude Control Experiment

2.2.1 Magnetic Torquer

To demonstrate various attitude control algorithm, such as three-axis stabilization, detumbling, and spin-up, with only magnetic torquers, Cute-1.7 is equipped with three magnetic torquers placed orthogonal to each other. Each torquer is a coil without iron core, whose dimensions are 50mm × 80mm × 4mm (Fig.3). Maximum magnetic moment is designed to be 0.037Am^2. Magnetic torquers have potential to be most useful actuator for such a tiny satellite. A magnetic torquer has no moving parts, requires only electricity and has structural simplicity. Nevertheless, control algorithm is a challenge, and therefore, it requires more study. Cute-1.7 will be a test bed for advanced magnetic torquer control, having capability of uploading control software.

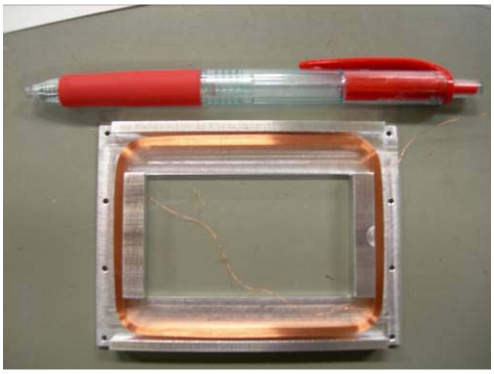


Fig.3 Magnetic Torquer

2.2.2 Attitude Determination

The satellite's attitude determination system is composed of a three-axis gyrosensor, a three-axis magnetometer, a sun sensor and a CMOS camera. The gyrosensor is a combination of three ADXRS gyroscopes by Analog Devices. The magnetometer is HMR2300 by Honeywell. The sun sensor is of most primitive type that is photodiode arrays, S6560 by Hamamatsu Photonics, attached to the surface of the satellite. Before making decision, other configurations of attitude sensor system was considered.

2.3 Amateur Radio Service – Digital Repeater

Through the experiences of using amateur radio frequency to operate CUTE-I, operators recognized that cooperation with radio amateur community is important. A lot of telemetry data from CUTE-I owes contribution by radio amateurs. Cute-1.7 will have functionality as an on-orbit message box open to public with uplink in 1200MHz band and downlink in 430MHz band. Since the satellite is planned to be inserted into low earth orbit, footprint of the satellite will not be so large and long distance communication via the satellite will not be possible. However, Cute-1.7 will enable communication between radio operators who are not in the same footprint simultaneously by storing and forwarding uploaded messages. Messages received by Cute-1.7 are stored and downlinked repeatedly for certain duration. The communication example is as shown in Fig.4. In this case, a message uploaded when Cute-1.7 passes over Japan is downloaded when over Australia.

We are planning to add on-orbit environment data or camera picture data to the uploaded message before download. In CUTE-I case, FM transmitter is operated only when CUTE-I passes over Japan, but that of Cute-1.7 is able to be used for operation all over the world during the time except for our planned mission occupies.

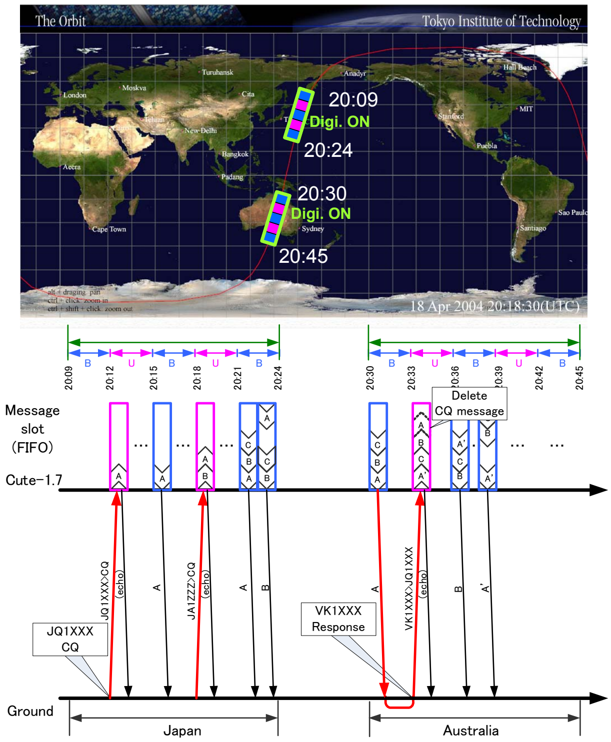


Fig. 4 Communication Example Using Digital Repeater

2.4 Tether Deployment Experiment

Small satellites are designed for short lifetime, and that are likely to be used as satellite constellation. The number of them should be large. Since the size of the proposed nanosatellite is comparable to the smallest size catalogued by U.S. Space Command, it might be untraceable. Thus, the issue of satellite disposal may not, be left untackled. Guidelines by the Inter Agency Space Debris Coordination Committee (IADC) are requiring all satellites in low-Earth orbit to be de-orbited within no more than 25 years.

To make an idea of satellite disposal system, the use of air drag by a deployed balloon was firstly considered. But simulation resulted in that a balloon with cross section of 110m^2 would be required for the satellite to reenter in 20years. The mass of the balloon would be more than 1kg with the material density of the balloon 0.1kg/m^2. It clearly means that this option is unrealistic for the proposed satellite.

Alternatively, the use of electrodynamic tether shown in Fig.5 was studied. Simulation resulted in that a 100m electrodynamic tether with 0.2mA current flowing can deorbit the satellite in 25years, assuming the tether is always perpendicular to the Earth magnetic field. Because a 100m tether does not generate enough voltage to achieve self-sufficiency, an additional power supply will be used to increase potential of the anode. The satellite deorbit system consists of a carbon nanotube electron emitter, a tether, a high voltage power supply and a tether end deployment mechanism[5].

To realize this system, there are several technological problems to solve, study of material for vacuum discharge, circuit for high voltage generation on such a small plate, way to wind tether up, stabilizing satellite attitude and straining tether perpendicular to the Earth magnetic field. Electro-dynamic tether system of nano -satellite for deorbit requires extremely advanced technology.

So we decided to conduct experiments to solve part of the problems mentioned above, tether deployment with a small mechanism. Fig.6 shows an image of this experiment. A part of the bottom plate separates from the body and extends below. A camera equipped on the side of the body monitors the condition of tether deployment.

The experiment mechanism is as shown in Fig.7. The left plate is a released unit, and the right is a separation device unit mounted on the body. These are connected with a conductive tether winded and stored in the separation device side, and the tether deploys when the plate is separated.

The separation plate is tied up with a nylon line to attach to the body. The nylon line is cut by electric current passed a nichrome line. This mechanism is originally used for the separation system of CUTE-I, and that of Cute-1.7 has also the same mechanism.

The separation experiment on the ground is scheduled in Microgravity Laboratory (MGLAB) this winter. Flight model will be fixed after the experiment.

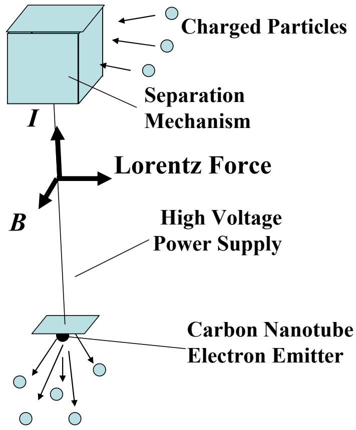


Fig.5 Tether Deorbit System

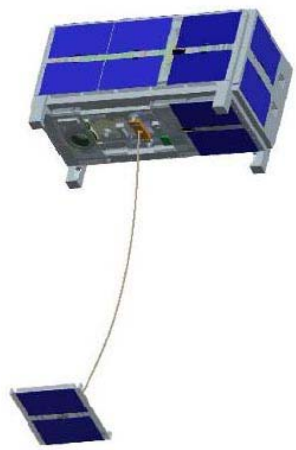


Fig.6 Image of Tether Deployment Experiment

Fig.7 Tether Deployment Mechanism

2.5 APD Demonstration

Cute-1.7 has a newly developed charged particle sensor by using Avalanched Photo Diode (APD) to observe LEO low energy charged particle density. APD was developed by Kawai Laboratory at department of Physics, Tokyo Tech. The characteristics of APD are very small, low power consumption, high speed of response and many others[6]. Fig.8 shows a APD sensor. If this on-orbit demonstration is successed, it is expected that APD is loaded into a large observation satellite or our next satellite[7] in the future.

Fig. 8 APD sensor

3. System Overview

Fig.9 shows thirty functional blocks in Cute-1.7. Thirteen blocks out of the thirty rely on finished products sold at ordinary electric goods stores, for example PDAs, memory cards, USB hub, digital cameras, handheld transceivers, and so on. Table 1 shows Cute-1.7 system configuration. In this table, the shortness of lifetime is due to the orbit condition described in the next section. For communication, CW beacon is transmitted with information of minimum house-keeping data. GMSK 9600bps packet communication is implemented and 1200MHz-band receiver is for digital repeater messages upload. All the devices are stored in double cube-sized body, as shown in Fig.10. Plumb is also equipped to achive about 3.5 kg in weight in order to extend the lifetime of the satellite.

Fig.11 is a separation system of Cute-1.7. The Main mechanism adheres fundamentally to CUTE-I. It consists of 4 jaws, two nylon lines and a heater shown in Fig.12. These jaws hold pillars of CUTE-1.7 and are tightened by the nylon lines. The nylon lines are heated to be cut. The jaws release the CUTE-1.7 pillars.

Separation experiments under microgravity environment were conducted on March 2005 at Microgravity Laboratory (MGLAB) in Japan, and the result was completely successed. Fig.13 shows a separation scene of the experiment. Total weight of Cute-1.7 and the separation system is 6.0kg.

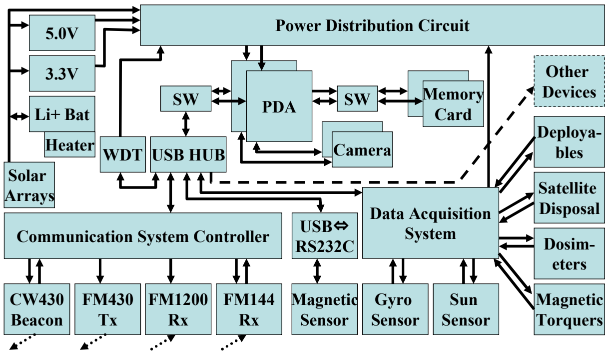
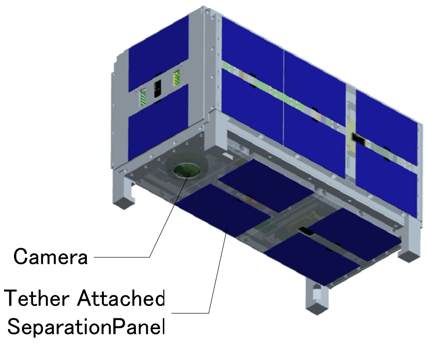


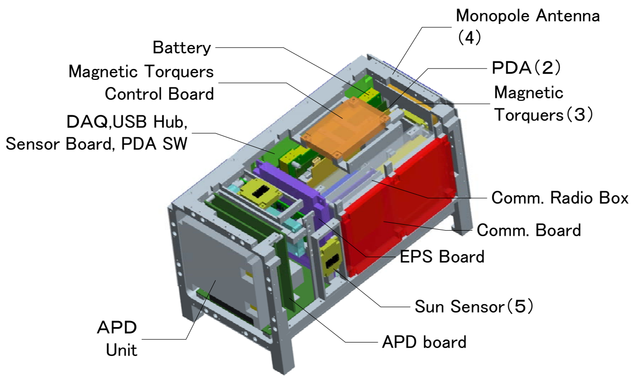
Fig.9 System Block Diagram

Table.1 Satellite Configuration

Size	10cm×10cm×20cm
Weight	3.5kg (Cute-1.7 body with plumb) 6.0kg (separation system included)
Life-time	2 weeks ~ 2 months
Mission	Attitude Control experiment Tether deployment Digital repeater APD sensor demonstration PDA demonstration
ADCS	Control：Magnet torquer Determination：Gyro, Sun sensor, Magnet sensor
C&DH	2 PDA (redundancy system), 4Mbit SRAM SD card data storage H8 DAQ, WDT
Comm.	144MHz-band Rx (command uplink) AFSK 1200bps / DTMF 430MHz-band Tx（beacon downlink） CW 430MHx-band Tx（Mission downlink） AFSK 1200bps / GMSK 9600bps PM 9600bps 1200MHz-band Rx (Service Uplink) GMSK 9600bps mono pole antenna
EPS	GaAs silicon cell (Power generation approx. 5W) Li-ion battery
Other Sensor	CF card camera Thermo meter Dosimeter Acceleration meter
Structure	Al5052 body (with stainless iron for plumb) Passive thermal control



(a) External View



(b) Equipment Layout

Fig.10 CG of Cute-1.7 + APD

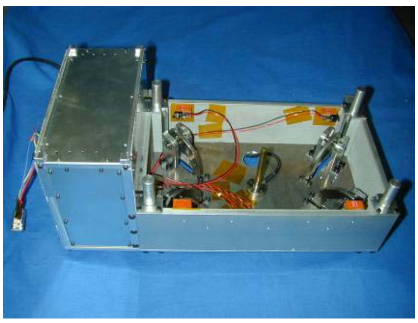


Fig. 11 Separation System

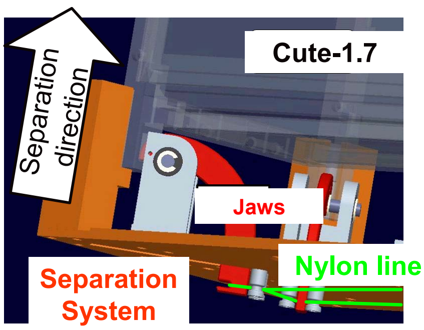


Fig. 12 Mechanism of Separation

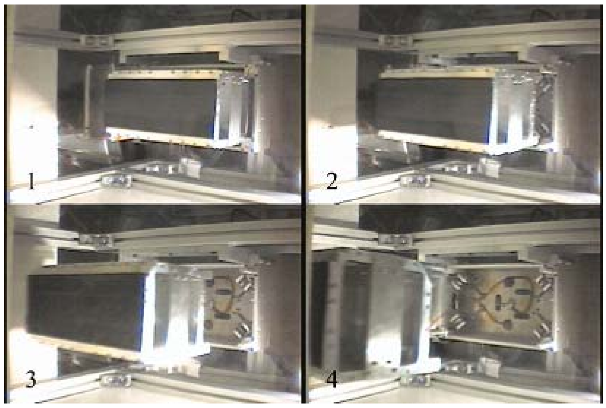


Fig.13 MGLAB Separation Experiment

4. Launch Rocket

Development of Cute-1.7 is aimed for the launch of JAXA/ISAS M-V Rocket#8 which loads "ASTRO-F" as a main satellite. We have already conducted an experiment for separation demonstration on M-V#6[8], and acquired the knowhow about rocket I/F. Launch date is scheduled to be February 2006. Detail of the orbit is as shown in Table 2.

Fig. 14 is the B3-PL unit which holds our Cute-1.7 to be released from the separation system shown in Fig.15.

Table 2 Detail of Orbit

Perigee height	185 km
Apogee height	800 km
Inclination	98.4 deg
Launch date	Feb 2006

Fig. 14 M-V Rocket B3-PL Unit

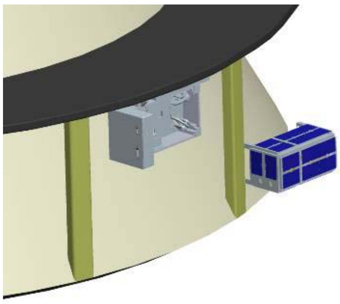


Fig.15 Separation Image

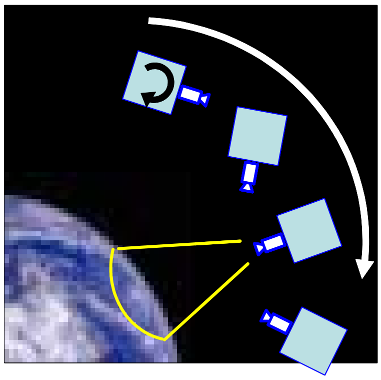


Fig.17 Photo Shoot Image

5. Disclosure of Acquired Data

We recognize that acquisition of enough telemetry data for mission could not be realized without cooperation of amateur radio users all over the world. We will ask them to communicate with Cute-1.7 and provide the acquired data to us. In return, we are planning to make visual analysis results from the gathered data. The Image of system is as shown in Fig.16. Anyone who communicates with Cute-1.7 can contribute to the Cute-1.7+APD missions, for example, a visual particle density map for APD mission.

By using a camera and magnet torquers, Cute-1.7 can take a picture of anywhere we want. Fig.17 shows an image of the Cute-1.7 shooting style. We will disclose any picture obtained from Cute-1.7 on our web site.

For people to feel familiar with Cute-1.7, we consider a small satellite weblog. According to raw telemetry data, LSS server makes the contents of weblog automatically. The system has already developed and is on a trial phase using the telemetry of CUTE-I[1]. We will prepare the same system for Cute-1.7+APD.

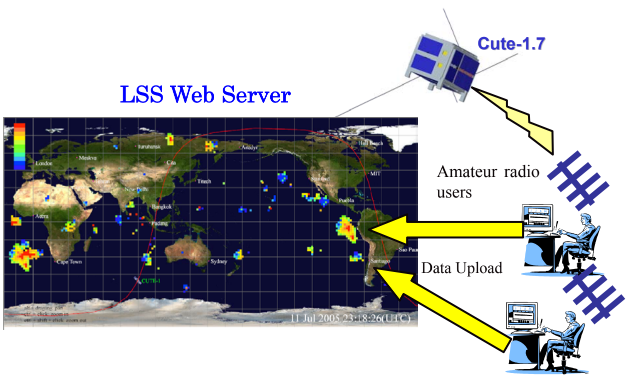


Fig. 16 Image of Data Uploading

6. Current Status and Future works

We have developed Post Flight Model (PFM) of as Cute-1.7 shown in Fig.18. Vibration test has conducted, and various environmental tests are scheduled from now. Then we will design flight model this autumn, and go on to final maintenance phase in winter. In addition, ground station for multi-satellites is needed to operate CUTE-I and Cute-1.7 and is now prepared. Status of development will be updated on our web site[9].

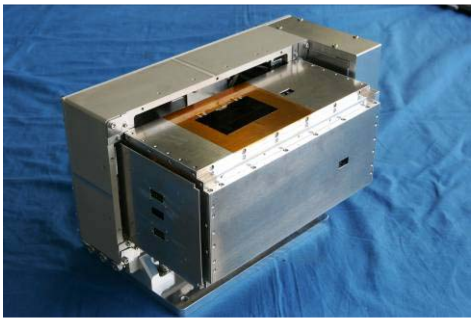


Fig.18 Cute-1.7 PFM + Separation System

7. Conclusion

In this paper, outlines of Cute-1.7 missions and systems are described. The missions are 1) PDA based OBC, 2) attitude control experiment using magnetic torquers, 3) amateur radio service – digital repeater, 4) tether deployment experiment, 5) APD demonstration. This satellite will be launched by M-V#8 in February, 2006. We hope the success of the Cute-1.7 and it improves the importance of micro-satellite existence.

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