Tokyo Tech CubeSat: CUTE-I
- Design & Development of Flight Model and Future Plan -

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Abstract

Laboratory for Space Systems, Tokyo Institute of Technology finished development of CUTE-I and is waiting for its launch on June 30, 2003. CUTE-I is the first CubeSat of Tokyo Institute of Technology, that is a 10 cm-edge cube-sized satellite of less than 1kg mass. CUTE-I has three missions such as communication, attitude sensing and deployment. to establish a bus component design for pico satellites like the CubeSat. In parallel with the CUTE-I development, we also developed a separation mechanism that is used to separate CUTE-I from the launcher on orbit. In this paper, we describe the design of CUTE-I and the separation mechanism as well as results of environment tests such as long-range communication test, thermal vacuum test, vibration test and separation test. We also mention a Tokyo Tech future plan on our satellite development.

Introduction

Laboratory for Space Systems (LSS), Tokyo Institute of Technology (Tokyo Tech), is participating in a CubeSat program that is an international, educational, and practical project proposed by Professor Robert Twiggs, Stanford University, at the 2nd University Space System Symposium (USSS) in Hawaii, November 1999. [8,10] "CubeSat" means that S3-SAT (Student, Space, Study Satellite), and that the shape of the satellite is cubic. In this project, more than forty universities are developing their small satellites of 10 cm cubic and less than 1 kg in weight around the world.[9] Tokyo Tech small satellite team finished development of the first TokyoTech CubeSat: CUTE-I (CUbical Titech Engineering satellite), and we are waiting for a launch on June 30, 2003 by a Russian rocket, Rockot in Plesetsk, Russian Federation.[1,3] Table 1 shows orbit information of CUTE-I.

Table 1 Orbit Information

Launch date	June 30, 2003
Place	Plesetsk (Russia)
Launcher	ROCKOT
Orbit Type	Circular
Perigee	820 km
Apogee	820 km
Inclination	98.7 degree

The first objective of this project is to establish bus component design for pico satellites. The second objective is to reduce the total development cost by using commercial off-the-shelf (COTS) components. These objectives are fulfilled under the leadership of students, so the students execute almost all of the activities such as design, assembly, planning, various tests, satellite operation and project management for developing and operating the satellite. In parallel with the development of CUTE-I, we also developed a separation mechanism. At the launch this separation mechanism will be used for CUTE-I release from the launcher on orbit.

In this paper, firstly, outlines of CUTE-I missions and systems are introduced. Secondly, design of the separation mechanism is described. Thirdly, we show results of various tests such as a long-range communication, a thermal vacuum and a vibration test as well as a separation test under micro-gravity environment. These tests were conducted to confirm design validities of CUTE-I and the separation mechanism. Fourthly, we refer future plans about a Tokyo Tech next CubeSat. Finally, we show conclusions.

General Outline of CUTE-I

MISSION

CUTE-I will conduct the following missions.
1) Communication mission
2) Sensing mission
3) Deployment mission

Communication Mission

The first objective of this mission is to receive satellite telemetry and to understand satellite conditions. The second objective is to compare Ax.25 and SRLL (Tokyo Tech original protocol). CUTE-I is equipped with a Tokyo Tech original CW-transmitter, which continuously transmits CW-telemetry including housekeeping data to a ground station (GS). Moreover, CUTE-I has a FM-transmitter and a receiver. The FM-Tx transmits FM-telemetry to the GS, which includes housekeeping data and payload data such as sensor data and so on using Ax.25 or SRLL protocols. The FM-Rx receives uplink commands in the form of DTMF (Dual Tone Multi Frequency) from the GS. We can change the communication protocol by a command uplink. In this mission, we use amateur frequency bands.

Ax.25 is a standard protocol that is very popular to amateur radio operators. Since there are a lot of Ax.25 decoders in markets, it is very easy to decode Ax.25 data. However, Ax.25 doesn't have a function for error correction. That is why that a packet is canceled if only one error bit is included in it. This is the defect of the Ax.25 protocol. In order to compensate this defect, we developed SRLL (Simple Radio Link Layer protocol). This protocol is derived from a protocol that is developed in the PRUG96 project of PRUG (Packet Radio User's Group).[11] SRLL deals with 32byte fixed length data packets. This protocol has a function for error correction, so that it can correct three error bits in one packet. We will switch these two protocols and inspect the validity of the SRLL protocol in the space communication using amateur frequency bands.

Sensing Mission

The objective of this mission is to gather various data for estimating a CUTE-I attitude and its condition in the space environment. CUTE-I has four small piezoelectric vibrating gyroscopes, four small accelerometers, thermometers and a CMOS sun sensor developed by LSS. The data of gyroscopes, accelerometers and the CMOS sun sensor are used to calculate the CUTE-I attitude. We can also get temperature data of various points of CUTE-I from thermometers. These data are very useful not only to understand the thermal distribution of pico satellites but also to correct sensor output that has drift depending on temperature. These data are stored in an on-board SRAM and transmitted by a command uplink from GS to estimate the CUTE-I three-axis attitude and the satellite condition. We expect that the data from this mission are very useful for our future development of pico satellites.

Deployment Mission

The objective of this mission is demonstration of our small deployment mechanism. Pico satellites like CUTE-I have a severe limit of its volume, so we tried to realize a small mechanism for deployment within the space limit. It is expected that such a deployment system will be usable in various missions. CUTE-I is equipped with a small motor mechanism to deploy a solar array paddle for getting enough electrical power, for example, to heat batteries: pico satellites are likely to become cooled down below 0 degree Celsius.

SUCCESS LEVEL

Tokyo Tech small satellite team set success levels of the CUTE-I Project in the following.

Minimum success is to study and acquire fundamental skills on design, development and an operation of a spacecraft. This criterion also includes tracking CUTE-I and receiving CW-telemetry.

Middle success is to acquire fundamental skills on communication technology. We try to receive FM-telemetry including the housekeeping data and monitor conditions of CUTE-I.

Full success is to acquire the advanced technology in communications and mechanisms. We try to change the communication protocols of FM-telemetry. In addition, we deploy the solar array paddle and demonstrate the small deployment mechanism we developed. Moreover, sensor data analysis to get the CUTE-I attitude is included in this success criterion.

SYSTEM

Figure 1 shows CUTE-I Flight Model.

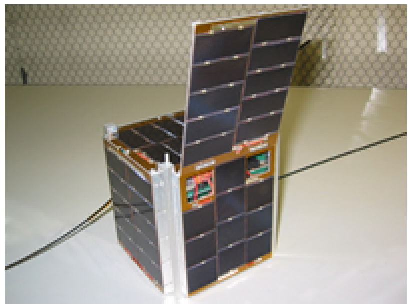

Figure 1 CUTE-I Flight Model

The system of CUTE-I consists of subsystems such as Sensor, Command & Data Handling (C&DH), Communication, Power and Structure. Figure 2 indicates the CUTE-I system block diagram.

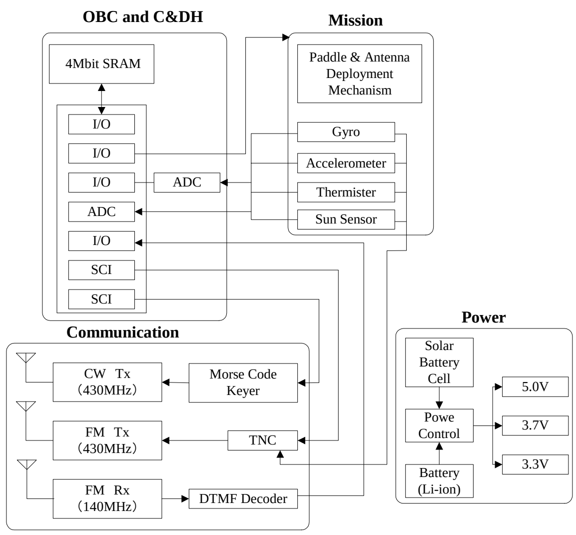

Figure 2 CUTE-I System Block Diagram

CUTE-I has a 430MHz band CW-transmitter, a 430MHz band FM-transmitter and a 140MHz band receiver. Thus the satellite is equipped with three deployable monopole antennas. In addition, it has the deployable solar allay paddle in order to generate electrical power. Moreover, CUTE-I has various sensors as described previously. The C&DH

subsystem gathers data from various sensors via A/D converters. These data are stored in an on-board memory or are outputted to a TNC to transmit them towards ground stations. At the same time, the TNC of the communication subsystem also gathers sensor data via TNC's A/D converters independently. In other words, we have two pathways for getting the sensor data. Therefore it is possible to get minimum data even if the C&DH subsystem has malfunctions. The power subsystem is composed of solar battery cells, a control circuit, and Li-Ion secondary batteries. This subsystem generates bus voltage 5.0V, 3.7V, and 3.3V.

Table 2 shows main components of CUTE-I.

Table 2 CUTE-I Main Components

Comm.	Tx 1	CW Tramsmitter Output 100mW
	Tx 2	FM Tramsmitter Output 350mW
	Rx	FM Reciever
	ANT	Monopole ×3
	TNC	Ax.25 1200bps (FSK)
		SRLL 1200bps (FSK)
		MPU: H8/300
	CW Keyer	MPU: PIC
Sensor	Gyro	4 axis
	Accelerometer	4 axis
	Sun Sensor	original
	thermistor	15 points
C&DH	MPU	H8/300
	Memory	4Mbit SRAM
Power	Battery	Li-ion
	Solar Cell	Si

OPERATION SEQUENCE

When CUTE-I is separated from a launcher, a power switch of CUTE-I is turned on. Then CUTE-I starts "Sensing Mission" and stores sensor data in its on-board memory. Initial data of this mission will be very useful to analyze the separating condition.

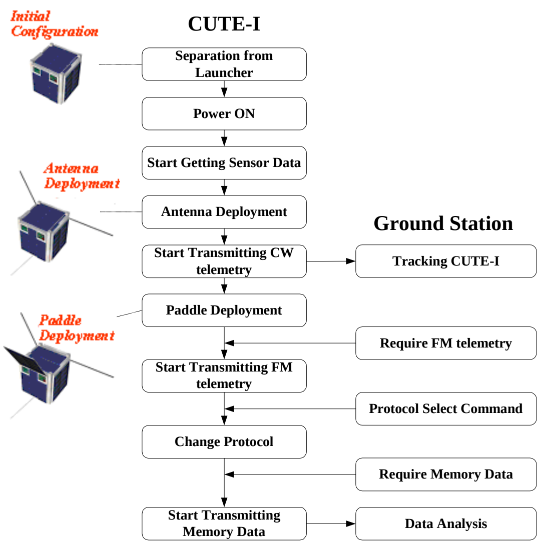

Figure 3 Operation Sequence

In a few minutes from the separation, CUTE-I starts "Deployment Mission" and deploys three monopole antennas and the solar paddle. After this sequence CUTE-I starts transmitting CW telemetry. When CUTE-I flies over the Tokyo Tech Ground Station, we tracks CUTE-I and measure the Doppler shift of the CW frequency to estimate CUTE-I orbital elements. After we can decide CUTE-I orbital elements, CUTE-I starts "Communication Mission". By receiving uplink commands, CUTE-I transmits FM-telemetry including sensor data using the Ax.25 protocol or Tokyo Tech original protocol (SRLL). Figure 3 shows the CUTE-I operation sequence.

SUBSYSTEM

In this section, each subsystem of the CUTE-I system is described. It consists of a sensor, a C&DH, a communication, a power and a structure subsystem as mentioned earlier.

SENSOR SUBSYSTEM

The sensor subsystem aims at acquiring attitude and thermal data of CUTE-I. This subsystem consists of two circuit boards shown in Figure 4. They are placed perpendicularly to each other in the CUTE-I structure. Each gyroscope can measure one axis angular velocity, so that CUTE-I can measure four axes angular velocity in total. Each accelerometer can measure two axes acceleration, so that CUTE-I can measure four axes acceleration. Acceleration data can also be translated into the angular velocity in order to compare with the data of the gyroscopes.

Figure 5 shows the CMOS Sun sensor circuit board. This sensor consists of a CMOS camera, a Control MPU and so on. Figure 6 indicates the block diagram of this sensor. The CMOS imager gets an image of space. If the sun is on the image, a luminance of the pixel, which the image data has, is very high. The sensor outputs a sun position on the image with the highest luminance pixel. The ground station calculates the sun angle on the body coordinates of CUTE-I by use of the sun position on the image.

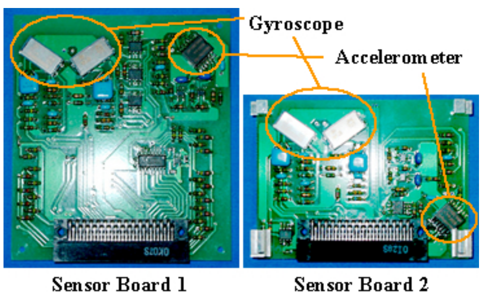

Figure 4 Sensor Subsystem Circuit Board

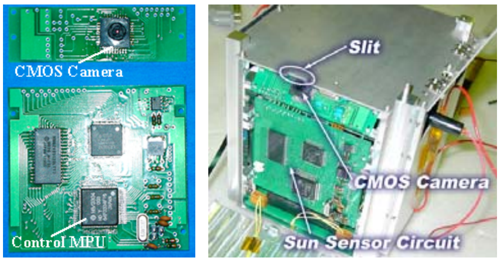

Figure 5 CMOS Sun Sensor Circuit Board

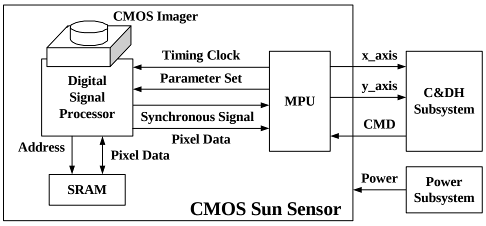

Figure 6 CMOS Sun Sensor Block Diagram

C&DH SUBSYSTEM

The C&DH subsystem is required to meet the following functions, 1) Get sensor data and store them in an on-board memory. 2) Detect DTMF commands from the GS and execute them. 3) Form data packets for downlinks and output them to the communication Subsystem.

Figure 7 indicates the system block diagram and the circuit board of the C&DH subsystem. CUTE-I has an 8 bit MPU as a main MPU and a 4 Mbit SRAM as a main data storage. This MPU has 8 channels A/D converter inside itself. However, we add more 16 channels since there are a lot of sensor data. Therefore, this system has 24 channels A/D converter in total. The main MPU stores 32 byte sensor data a sampling. By a command uplink, a sampling rate can be changed from 100 msec intervals to 3 min. intervals. In case of reading the memory data and transmitting them, the main MPU sends 32 byte data as one packet to the communication subsystem. An interval of sending data can be changed from 1sec. to 30 sec. by a command uplink.

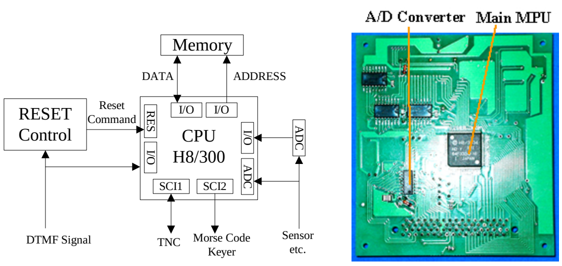

Figure 7 C&DH System Block Diagram and Circuit Board

COMMUNICATION SUBSYSTEM

Functions of the communication subsystem are as followings. 1) Receive a series of DTMF uplink commands. 2) Downlink FM-telemetry packets including payload data. 3) Downlink CW-telemetry that includes HK data. 4) Change communication protocols.

Figure 8 shows the communication subsystem block diagram. CUTE-I has a CW transmitter, a FM transmitter and a FM receiver, which have a monopole antenna individually. The FM transmitter output power is 350 mW and the CW transmitter output power is 100 mW. Uplink commands from a ground station to the CUTE-I consist of some DTMF signals, and each DTMF signal includes 4 bit data. A TNC (Terminal Node Controller), which has a data encoding function, consists of a MPU and a modem IC. Software that can encode both the Ax.25protocol data and the SRLL protocol data is implemented in the MPU. The TNC gets data from the C&DH subsystem via a serial communication line. This subsystem has another small MPU as a CW generator. This MPU gets data from the C&DH subsystem via a serial communication line and generates CW signals.

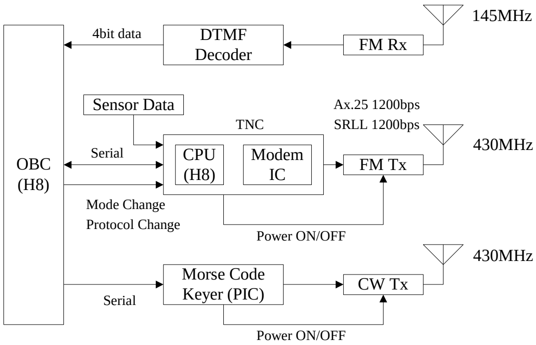

Figure 8 Comm. System Block Diagram

POWER SUBSYSTEM

Functions of the power subsystem are as followings, 1) Provide and control electrical power generated by solar cells, 2) Share solar power appropriately between bus components and a Li-Ion battery charger, 3) Regulate voltage (3.3V and 5.0V) in high efficiently, 4) Measure voltage/current of cells, Li-Ion charge/discharge current and bus voltage, 5) Detect over-current generated by SEL, and shutdown main bus immediately.

Table 3 and Table 4 show the specification of the solar cell and Li-Ion battery.

Table 3 Specification of Solar Cell

Cell Size (W,T,H)	27 x 24 x 0.1mm^3
Type	Silicon Solar Cells
Voc	6180mV
Isc	321mA
IL(5.0V)	304mA
IL(4.5V)	313mA
P(4.5V)	1.4085W
Temp.(operation)	-150～140℃
IL	1038mA
Efficiency	16.90%

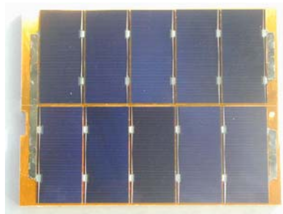

Table 4　Specification of Li-Ion Battery

Nominal Capacity		1040mAh
Nominal Voltage		3.8V
Charging Voltage		4.2+/-0.05V
Cathode Materials		Mn
Anode Materials		Graphite
Dimensions (W,T,H)		33.8 x 6.5 x 66.6mm
Cycle Life		500cycle
Operationg Temp Range	Charge	-0'C to 45'C
	Discharge	-20'C to 60'C
Weight		32g

STRUCTURE SUBSYSTEM

The structure subsystem consists of CUTE-I structures and deployment mechanisms for the antennas and the solar paddle.

STRUCTURE

Since there are shape limit, 10cm × 10cm × 10cm, and weight limit, less than 1kg, it is very important to achieve an efficient configuration of satellite components, and lightweight design. Figure 8 shows the CUTE-I structure. The main structure consists of four pillars and walls. Figure 9 indicates the CUTE-I component configuration. As shown in Figure 9, we use layer structure to hold circuit boards, so that we can save space.

We also use Mg alloy for some structure parts to achieve lightweight structure as shown in Figure 10.[2,4]

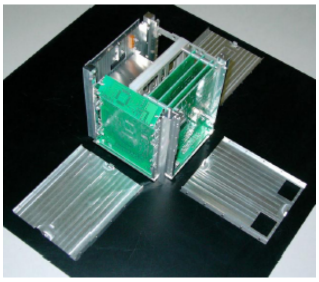

Figure 8　CUTE-I Structure

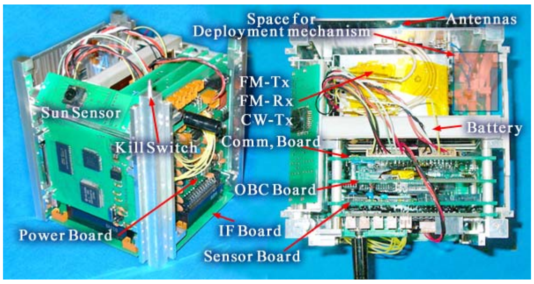

Figure 9　CUTE-I Component Configuration

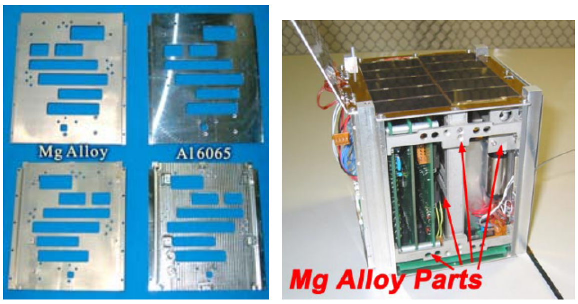

Figure 10　Mg Alloy Parts

DEPLOYMENT MECHANISM

CUTE-I has the deployable solar array paddle and three monopole antennas. A mechanism for this paddle is composed of a spring hinge, a paddle stopper and a small vacuum DC motor. This motor removes the stopper. Then the paddle opens passively by the spring force. Figure 11 shows the paddle deployment mechanism. Figure 12 shows the paddle deployment operation.

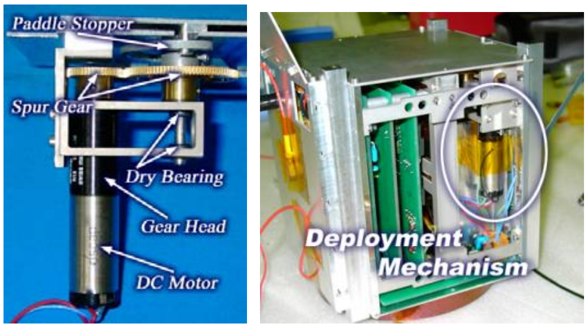

Figure 11　Paddle Deployment Mechanism

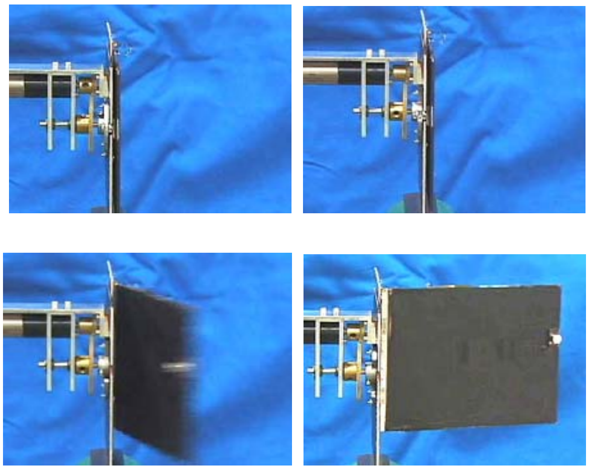

Figure 12　Paddle Deployment Operation

The antenna deployment mechanism is constructed of a Nichrome heater and nylon wire. After CUTE-I is separated from a launcher and the power is turned on, communication antennas are deployed and CUTE-I starts to transmit CW-Telemetry. Figure 13 shows an image of the antenna deployment mechanism.

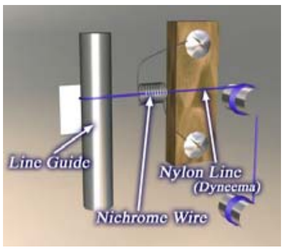

Figure 13　Antenna Deployment Mechanism

Separation Mechanism

In this section, a separation mechanism that is used for separating CUTE-I from a launcher is mentioned. Separation mechanisms developed for big satellites generally use pyrotechnic devices. However, we consider that the pyrotechnic system is not suitable for the CUTE-I separation mechanism because of the reasons in the following. Firstly, application of pyrotechnic devices to a separation mechanism for pico satellites such as CUTE-I causes some troubles because of hard mechanical shock of the pyrotechnic blast. Secondly, it is difficult for students to use pyrotechnic devices because they are generally dangerous devices. Therefore we developed a separation mechanism that doesn't use pyrotechnic devices. This mechanism is shown in Figure 14. Figure 15 represents the mechanism equipped with the CUTE-I structure model.

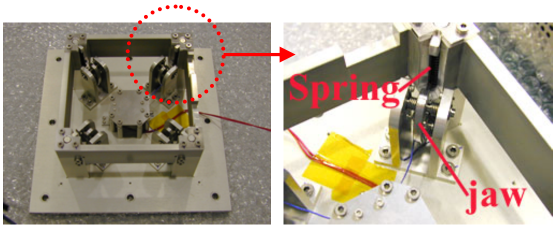

Figure 14 Separation Mechanism

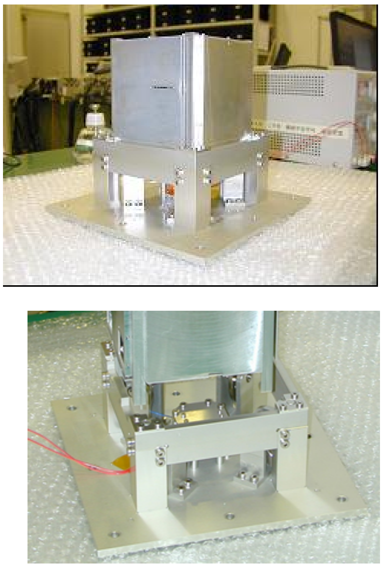

Figure 15 Separation Mechanism with CUTE-I

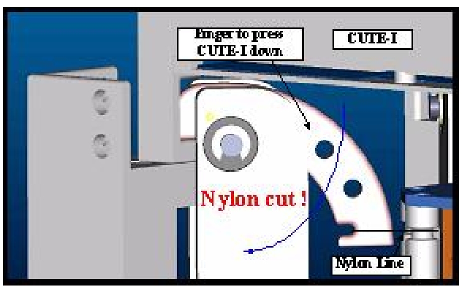

Figure 16 Mechanism Image

This mechanism consists of 4 jaws and a nylon line. These jaws hold pillars of CUTE-I and are tightened by the nylon line as shown in Figure 16. When the nylon line is heat to be cut, the jaws release the CUTE-I pillars. Then springs inside the mechanism push CUTE-I, and separate it. A characteristic of this mechanism is the simplicity of the mechanism, so that lightweight is achieved. We can also adjust separating velocity by changing springs. This is another feature of this mechanism.

Environment Test

We conducted various environment tests such as a long-range communication test, a thermal vacuum test, a vibration test and a separation test under the micro-gravity environment to confirm validities of our design for CUTE-I and the separation mechanism. Results of them were very useful for us to improve the CUTE-I design. These environment tests are described in the following sections.

Long-Range Communication Test

We conducted a long-range communication test at Sanriku city, Iwate, Japan on May 2001.[5] This test was supported by The Institute of Space and Astronautical Science (ISAS). A balloon as shown in Figure 17 was equipped with the CUTE-I communication subsystem.

Figure 17 Balloon with Comm. Subsystem

The objective of the experiment was to check long-range properties of the CUTE-I communication subsystem. The Balloon had an ISAS transceiver, so that we could get housekeeping data even if the CUTE-I communication subsystem had some troubles. Results of the experiment are as followings.

1) During the experiment, our Sanriku ground station always could receive CW-telemetry. Tokyo Tech ground station in Tokyo, that is 450 km far away from Sanriku, also could receive them.
2) The balloon couldn't receive command uplinks when it was about 10 km far away from the Sanriku ground station.
3) The Sanriku ground station couldn't receive FM-telemetry from the balloon when it was about 40 km far away.

Figure 18 and 19 indicate the balloon altitude and the distance between the balloon and the Sanriku ground station. The numbers in these graphs correspond to event numbers of Table 5. Figure 20 indicates temperature data from CUTE-I telemetry.

When the event 2 occurred, Figure 20 indicates that temperature of the FM receiver was about 28 degree Celsius. This is normal temperature. Temperature was around 0 degree Celsius, that is also normal temperature, at the event 3 and 4. Therefore the reason of the troubles is not concerned with temperature.

After the experiments we carefully investigated the CUTE-I communication system. Then we found the following problems.

1) The multiply circuit we used inside the CW transmitter generated an intermediate frequency 145.7MHz in the process of generating the CW transmit frequency 436.835MHz. 145.7MHz is very close to the frequency of the FM receiver, and therefore, the FM receiver sensibility was suppressed. That is why that the CUTE-I receiver couldn't receive command uplinks.
2) Shields between communication devices were not enough.
3) Antenna matching were not enough.

From the results the communication subsystem of CUTE-I Flight Model was improved as follows. Firstly, we changed a fundamental frequency of the CW transmitter, so that it doesn't generate the intermediate frequency that is close to the frequency of the FM receiver. Secondly, we made a shield box to isolate each communication devices. Finally, we made improved matching circuits for each antenna.

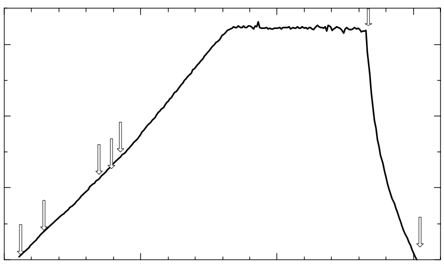

Figure 18 Balloon Altitude

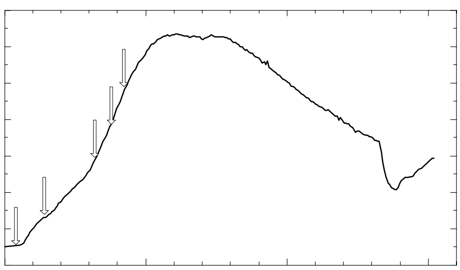

Figure 19 Distance between Balloon and Sanriku Ground Station

Table 5 Event List

	JST	Event
1	7:37	Balloon was Released
2	7:54	Command (Titech UpLink) from Ground Station was not received.
3	8:29	We can not demodulate the data of Ax.25 packet.
4	8:34	We can not demodulate the data of SRLL packet.
5	8:39	We can not receive any FM RF signals.
6	11:11	Satellite was separated from Balloon.
7	11:42	Splashdown.The transmisson of CW transmitter was ended.

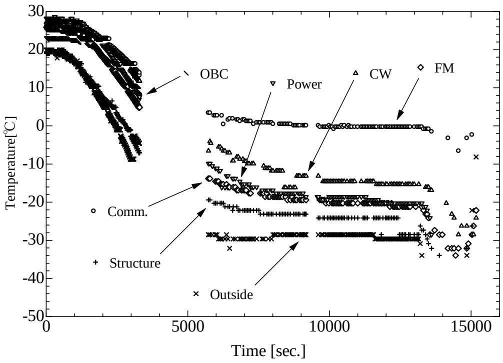

Figure 20 Telemetry Data (temperature) from CUTE-I Comm.

THERMAL VACUUM TEST

A thermal vacuum test of CUTE-I was conducted to measure and observe a thermal equilibrium status and performance of components on thermal vacuum environment. Moreover, we compared the result of the test with that of a thermal simulation. Figure 21 shows the space chamber used for this test, and Table 6 represents measuring points. This test was supported by ISAS.

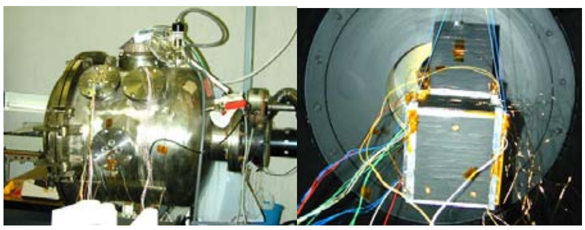

Figure 21 Space Chamber

Table 6 Measuring Point and Number

Structure	Shell	8
	Column	4
	Paddle	1
	Battery Box	1
	Comm. Box	1
Components	Circuit	7
	FM-Tx	1
	FM-Rx	1
Other	Chamber	3

A system block diagram of the thermal vacuum test is shown in Figure 22. To simulate the heat input of sunlight ($1300W/m^2$), nichrome wires are put on surfaces of the CUTE-I structure.

The result of a single surface heat input experiment is shown in Figure 23. We can see from the graph that the temperatures of all components and structure are always below 0 degree Celsius. In this condition, CW transmitter had no problem and could work well, however the FM transmitter didn't operate. The reason of this phenomenon is that the very low temperature of Li-Ion battery, that is under -20 degree Celsius, weakens its output current. In this situation, performance of the battery is 1/8 compared with that in normal temperature. Therefore, the FM transmitter could not operate.

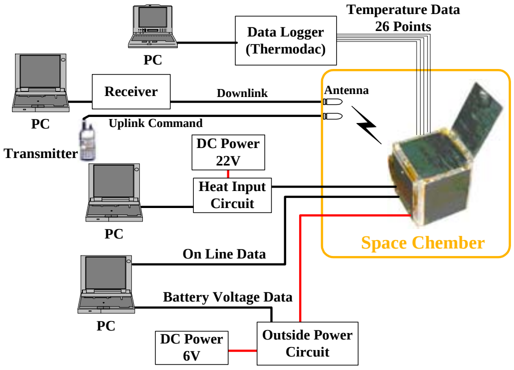

Figure 22 System Block Diagram

These results of the thermal vacuum test give us guidelines, which indicates, for example, that the temperature of the battery is very important to decide a timing of turning on the FM transmitter. We will have to be monitoring the component temperature, especially battery temperature, to plan operation sequence of CUTE-I on orbit.

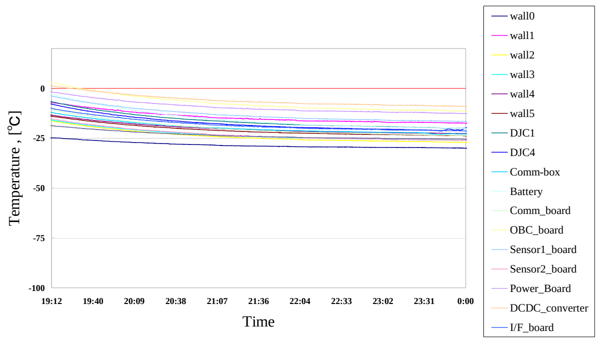

Figure 23 Result of Thermal Vacuum Test

In parallel with the thermal vacuum test, we simulated the thermal equilibrium of CUTE-I by simulation software. The result of the simulation was compared with that of the test as shown in Table 7. These data from the test and simulation are considered to approximately agree with each other. We consider that many thermo couples that were attached to CUTE-I in order to measure temperature conducted heat to the outside of the space chamber, so that there were some differences of the result between the experiment and the simulation.

Table 7 Simulation Result

	Experimental, [℃]	Simulation, [℃]
Paddle	-0.5	11.6
Battery	-4.7	-16.3
Comm_Board	-9.6	-4.4
OBC_Board	-1.9	-7.2
Sensor_Board	-8.4	-11.1
Power_Board	-15.6	-4.6
Comm_Box	-4.6	-10.8
IF_Board	-5.2	-14.9
Wall_5	11.3	8.7

VIBRATION TEST

We conducted vibration tests at Tukuba Space Center NASDA, Japan on November 2002. These tests were supported by Micro Space System Lab. , NASDA.

The objective of the tests was to confirm that the CUTE-I launch system including CUTE-I and its separation mechanism would be able to endure vibration environment of the CUTE-I launch. We conducted three kinds of vibration tests, which are a modal vibration test, a sinusoidal oscillation test and a random vibration test. Each test was conducted along the X-axis, which was perpendicular to the separation direction, and the Z-axis, which was parallel to the separation direction. The spectral level of the vibration was set to be 125% of the vibration condition of the "ROCKOT" that is used to launch CubeSats on June 2003. Figure 24 shows the experimental setup.

Figure 24 Experimental setup

Results of the vibration tests are in the following. The separation mechanism certainly kept holding CUTE-I during the experiments, so that we consider that the CUTE-I launch system including CUTE-I and the separation system will endure a real launch. However, the result of the Z-axis random vibration indicates that power spectrum of CUTE-I wall-4 is 51.65Gr^2 responding to 506 Hz input. This phenomenon occurred because the natural frequency of the wall-4, that was 531Hz, was close to the rocket frequency 480-520Hz as shown in Figure 25. This result shows the necessity for improving the wall-4 design.

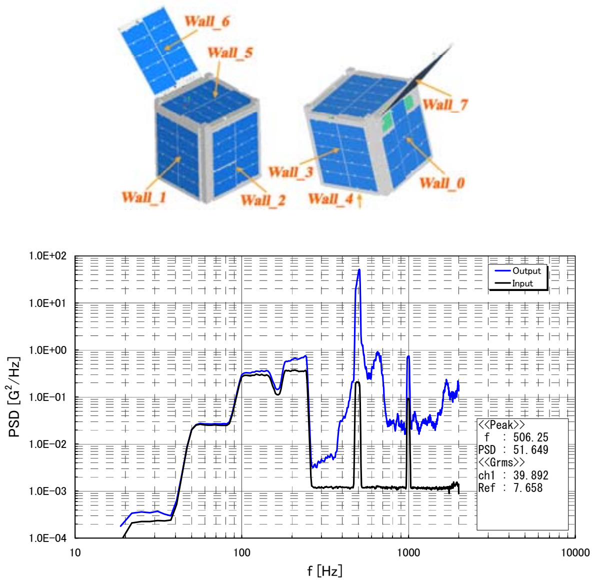

Figure 25 Result of Wall-4 in Random Vibration Test

SEPARATION TEST UNDER MICRO-GRAVITY ENVIRONMENT

We conducted a separation test under micro-gravity environment at the Japan Micro gravity Center (JAMIC), Hokkaido, Japan on December 2002.[12] JAMIC has a drop shaft system to generate micro-gravity environment. It can achieve 10^{-5} order micro-gravity for 10 seconds. The objective of this test was to estimate a separation velocity and an attitude disturbance of the CUTE-I separation. Experimental setup is shown in Figure 26. In order to measure these values we used two CCD cameras and four PSD sensors. Figure 27 shows the system block diagram.

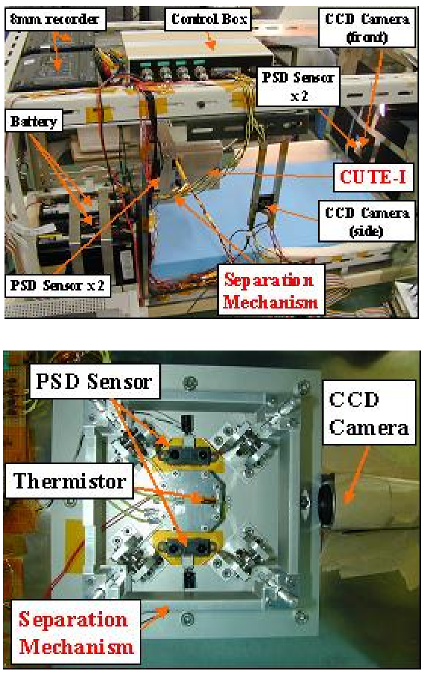

Figure 26 Experimental Setup

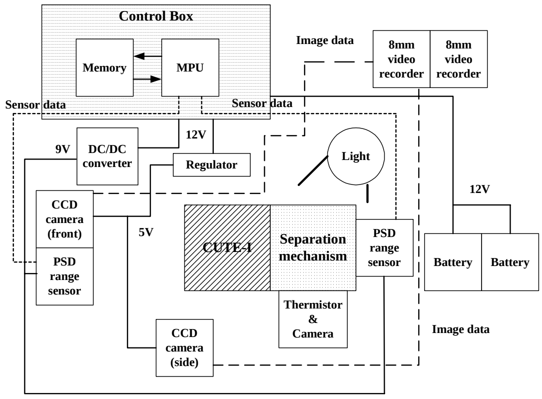

Figure 27 System Block Diagram

Two experiments were conducted. In the second experiment, springs that had a weaker constant were used to change a separation velocity. Table 8 shows the separation velocity measured in these experiments. Predictions were calculated with neglecting frictions between CUTE-I and the separation mechanism. That is why we consider that experimental data are different from the prediction value. Figure 28 shows the CCD camera image during the experiments.

Table 8 Results: Separation Velocity

	Image processing (cm/s)	PSD sensor (cm/s)	Prediction value (cm/s)
1st Day	108.75	106.95	141
2nd Day	45.31	50.81	75.4

Figure 28 CCD Camera Image

Results of the separation tests are mentioned in the following. Firstly, we confirmed that the separation mechanism worked well under micro-gravity environment. This was simplest result, however, we consider it is very important to check this fact. Secondly, we confirmed there was little attitude disturbance, and CUTE-I was separated on the straight. This is satisfied the requirement from a rocket company. Thirdly, we could find an appropriate spring constant for the separation velocity that is required by the launch rocket, that is 20 cm/s – 100 cm/s.

FUTURE PLAN

In this section, a future plan of Tokyo Tech small satellite program is mentioned. Our satellite development activities are classified as two types as shown in Figure 29. One is an educational-oriented satellite development such as CUTE-I. The objective is focused on student education, so that students execute almost all the activities and obtain a lot of experience in the process of developing a whole system of very small sized satellite. A continuation of the educational-oriented satellite development is very important.

The other is a research-oriented development and the objective is research and development of advanced space systems, for example, a novel device of a satellite such as an advanced attitude control device, MEMS sensor and actuator. The Tokyo Tech small satellite team started two development projects: 1) a gamma ray burst observation satellite of 50kg class in cooperation with a laboratory of the faculty of science, Tokyo Tech, 2) a new type of solar sail vehicle in cooperation with ISAS.[6, 7]

To practice both of the educational-oriented development and the research-oriented one is especially important for university laboratory activities, and we can make a contribution to future space developments.

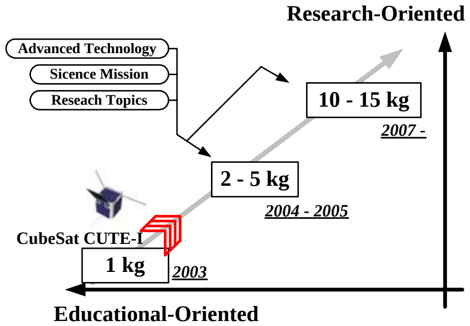

Figure 29 Future Plan of Tokyo Tech Small Satellite Project

CONCLUSION

In this paper, we explained the summary of the Tokyo Tech CubeSat CUTE-I development. The missions of CUTE-I and the satellite system were described, and the operation sequence was also mentioned. The detailed design of CUTE-I subsystems such as sensor, C&DH, communication, power and structure were explained, and the separation mechanism that will be used to launch CUTE-I on June 2003 was also introduced. The results of various environment tests were mentioned to verify the CUTE-I design. From the results, we were able to improve the design of CUTE-I as much as possible. Finally, The future plan of the Tokyo Tech small satellite team was mentioned. We have started the research-oriented satellite development projects, while we continue the educational-oriented one such as CUTE-I.

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