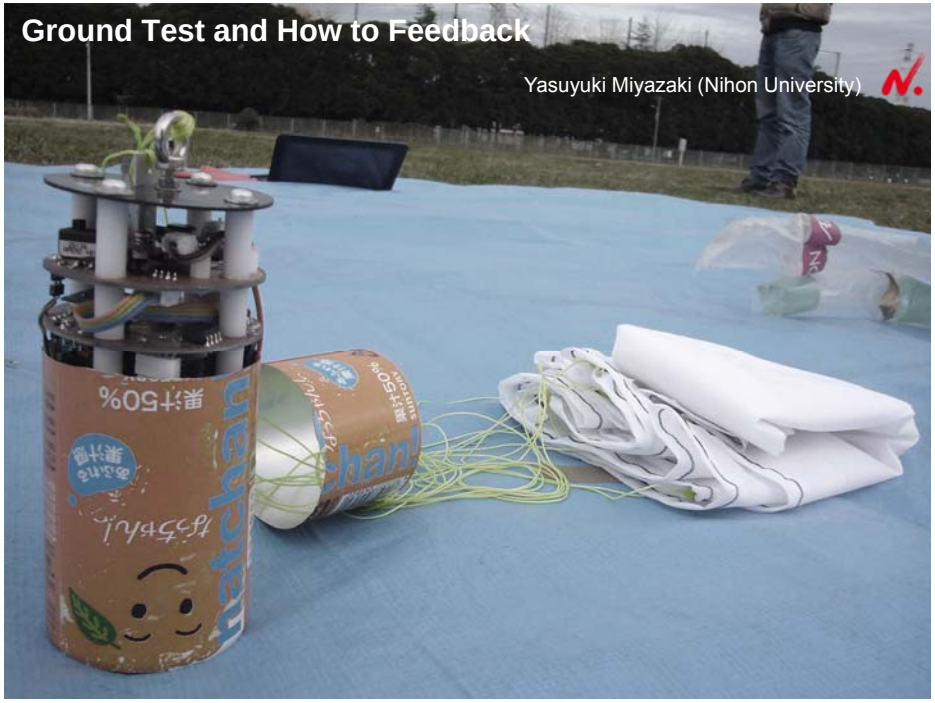
Ground Test and How to Feedback

Yasuyuki Miyazaki (Nihon University)



Self-introduction

- **Before 1999**

No activity on satellite development (only paper project)

Satellite Design Contest (1999)

Laboratory (1994)

Self-introduction

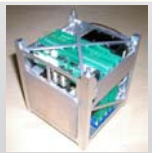
- **Cansat Launch in ARLISS (2000-)**
  - ✓ Launch of Cansat to 4km altitude by model rocket
  - ✓ We started Cansat project (half year project) in 2000
  - ✓ Cansat project is a training for pico-sat development

Organized by UNISEC

ARLISS (2000)

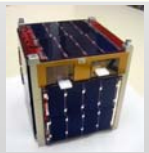
- **First pico-sat development (2001-2004)**
  - ✓ First challenge for “real” space development
  - ✓ Flight results of pioneer laboratories (U. Tokyo, Tokyo Tech) were quite valuable and were utilized to improve the design and development of our CubeSat

BBM (2002)



EM-1 (2003)

EM-2 (2004)



FM “SEEDS” (2004)

Self-introduction

- **First pico-sat launch (July 2006)**
  - ✓ International collaboration of cluster launch of 18 satellites including 14 CubeSats arranged by CalPoly
  - ✓ Launch by Dnepr-LV7 from Baikonur Cosmodrome
  - ✓ Launch failure by trouble of 1st stage engine of Dnepr

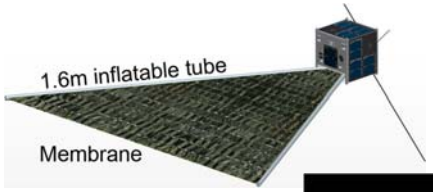
SEEDS-1 (2006)

- **Second pico-sat launch (April 2008)**
  - ✓ Cluster launch of 10 satellites arranged by University of Toronto
  - ✓ Delivered to Toronto in June 2007
  - ✓ Launched in April 28th 2008 by PSLV-C9 from Satish Dhawan Space Center in India.
  - ✓ Misson: Downlink of HK data, attitude data, Digi-talker, SSTV

SEEDS-2 (2008)

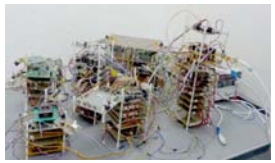
Self-introduction

- **Development of 3rd pico-sat (2006, 2009-)**



SPROUT

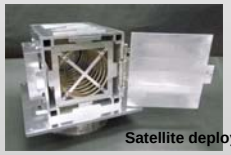
Cansat (2006)



BBM (2012)

EM (2013)

- ✓ 20cm cube, 6.7kg
- ✓ Demonstration of inflatable membrane structure for future large space structure mission
- ✓ Earth photo by CMOS camera
- ✓ Experiment of attitude determination and control
- ✓ will be launched in 2014 by Japanese H-IIA rocket



Satellite deployer (2013)

Ground Test and How to Feedback

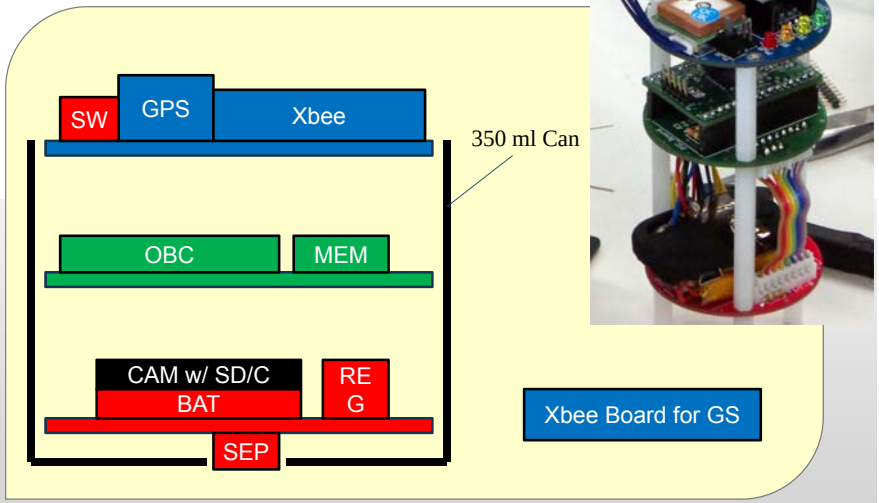
Yasuyuki Miyazaki (Nihon University)

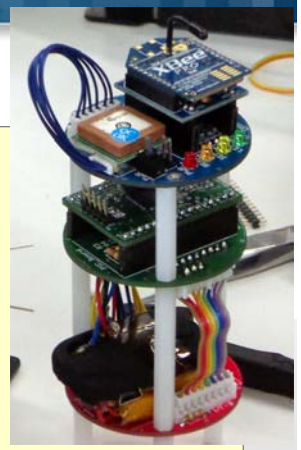
CONTENTS

1. Introduction
   - ✓ System Architecture of CLTP4 CanSat
   - ✓ Example of Development process
2. What is the purpose of ground test?
3. What can we verify in ground test?
4. What can we feed back test results?

INTRODUCTION

System Architecture of CLTP4 CanSat

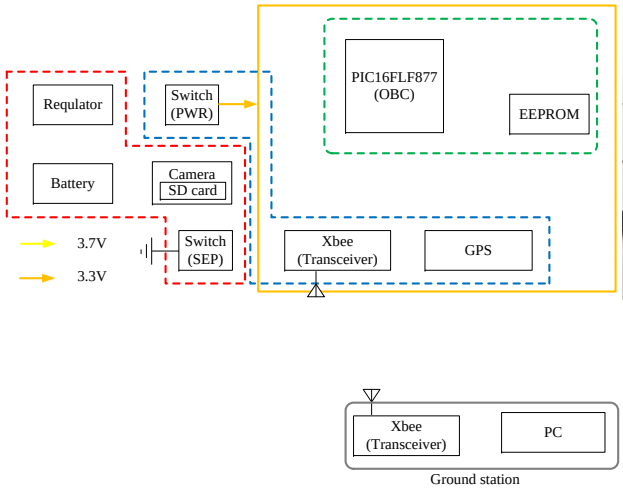


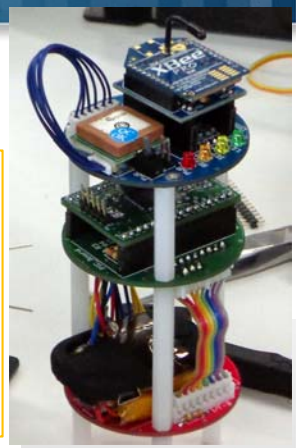


INTRODUCTION

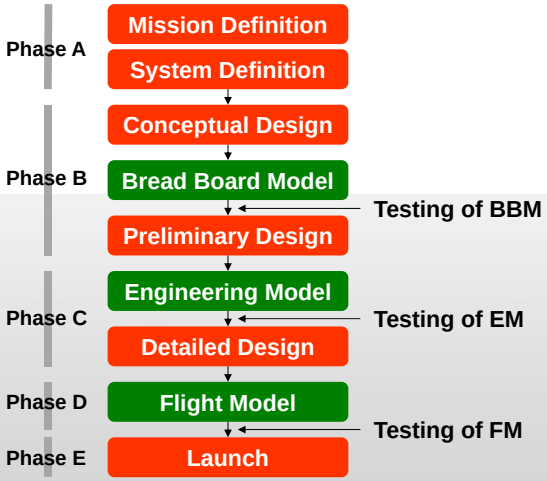
System Architecture of CLTP4 CanSat

Would you draw the lines between the components? (power lines, signal lines, etc.)





Example of Development Process (Satellite)



Example of Development Process (CanSat)

1) Assemble "kit" with fixed mission, do ground test and launch/balloon experiment
   1-1) Add original mission with new components
2) Create mission, obtain (purchase) subsystem components, do ground test and launch/balloon experiment
   2-1) Design/fabricate some components
   2-2) Design/fabricate all the components

Prof. Nakasuka's 2nd lecture

	Mission creation	Architec-ture design	System Analysis	Sub system design	Project manage-ment	AI&T
1)					s	s
1-1)	s	s	s		s	s
2)	Y	Y	Y		Y	Y
2-1)	Y	Y	Y	s	Y	Y
2-2)	Y	Y	Y	Y	Y	Y

Note) AI&T Assembly, Integration and Test s:small effect Y:large effect

Example of Development Process - CanSat 1)

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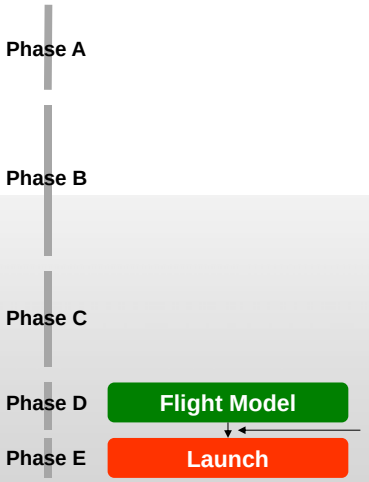

Example of Development Process - CanSat 1-1)

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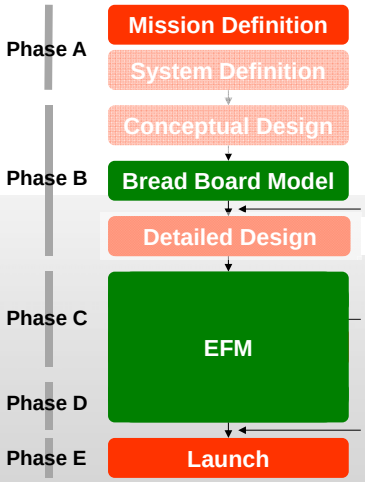
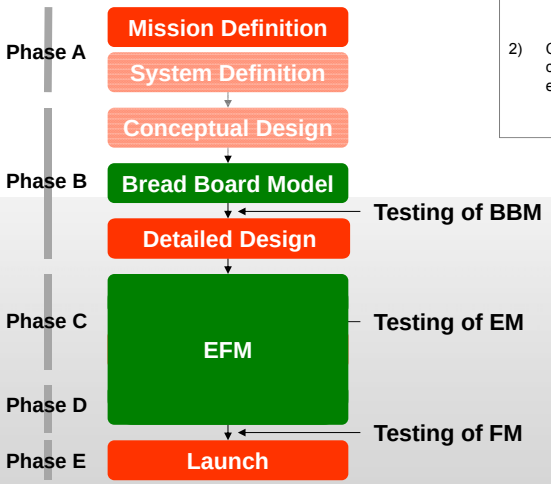


Example of Development Process - CanSat 2)

1) Assemble "kit" with fixed mission, do ground test and launch/balloon experiment
   1-1) Add original mission with new components
2) Create mission, obtain (purchase) subsystem components, do ground test and launch/balloon experiment
   2-1) Design/fabricate some components
   2-2) Design/fabricate all the components



	Mission creation	Architec-ture design	System Analysis	Sub system design	Project manage-ment	AI&T
1)					s	s
1-1)	s	s	s		s	s
2)	Y	Y	Y		Y	Y
2-1)	Y	Y	Y	s	Y	Y
2-2)	Y	Y	Y	Y	Y	Y

Note| AI&T: Assembly, Integration and Test s:small effect Y:large effect

Example of Development Process - CanSat 2-1), 2-2)

1) Assemble "kit" with fixed mission, do ground test and launch/balloon experiment
   1-1) Add original mission with new components
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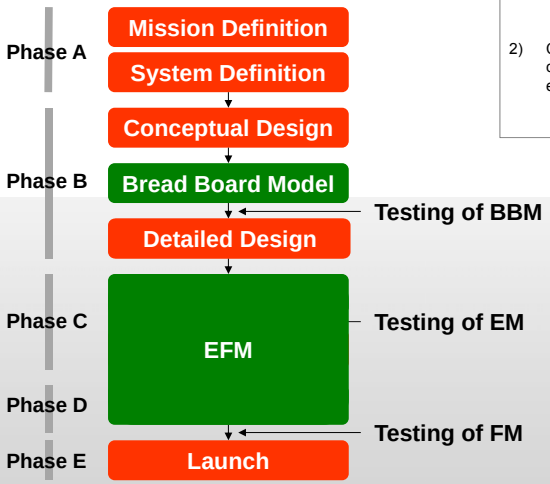

	Mission creation	Architec-ture design	System Analysis	Sub system design	Project manage-ment	AI&T
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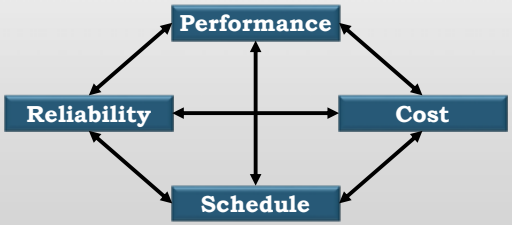
1-1)	s	s	s		s	s
2)	Y	Y	Y		Y	Y
2-1)	Y	Y	Y	s	Y	Y
2-2)	Y	Y	Y	Y	Y	Y

Note| AI&T: Assembly, Integration and Test s:small effect Y:large effect

Purpose of Ground Test

To confirm that our satellite will work perfectly and we will achieve the mission

- To verify the design and development, i.e. to verify that the satellite system will work well in space as we expect.
- To assure the performance and the reliability of the system combined with theoretical (numerical) analysis, i.e. to reduce the risk of mission failure as low as reasonably practical (ALRP) under some uncertainty and restriction of the cost and schedule (development time).
- To feedback the test results to FM (in case of ground test of EM)



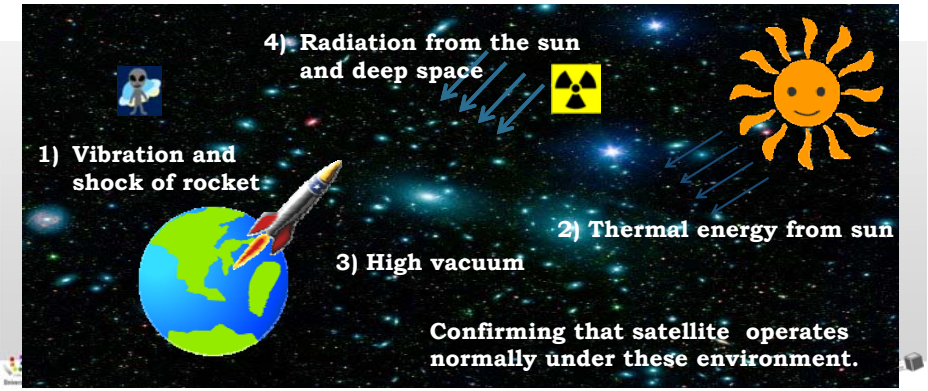
Purpose of Ground Test

To confirm that our satellite will work perfectly and we will achieve the mission

❖ Environmental test

✓ To verify that the satellite is tolerant of launch environment
✓ To verify that the satellite is tolerant of space environment

← Some of them are required by launch provider.



WHAT IS THE PURPOSE OF GROUND TEST?

Purpose of Ground Test

To confirm that our satellite will work perfectly and we will achieve the mission

- ❖ Environmental test
  - ✓ To verify that the satellite is tolerant of launch environment
  - ✓ To verify that the satellite is tolerant of space environment

  ← Some of them are required by launch provider.

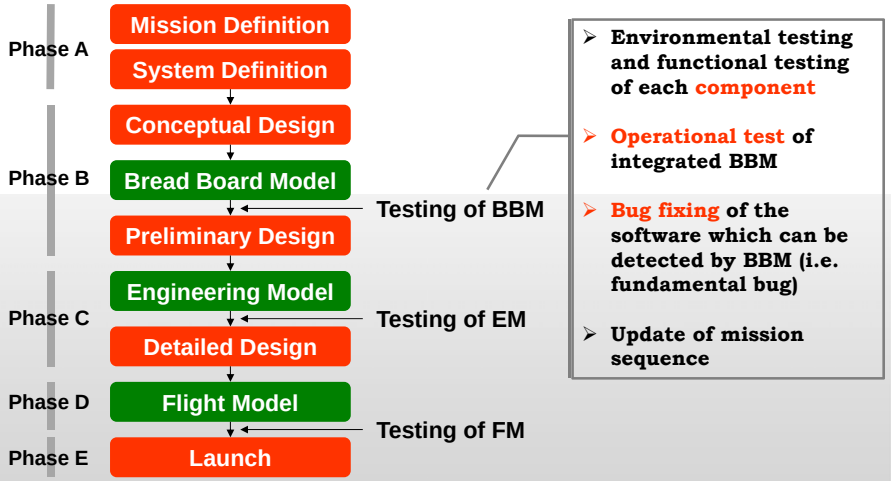
- ❖ Operational test (End-to-End test)
  - ✓ To verify that the satellite works as we expect

  ← Some of them are required by launch provider.

We should imagine the whole life of the satellite (from the delivery to the launch provider to the shut-down in space), and conduct the testing to confirm that our satellite works well during the mission.

WHAT CAN WE VERIFY IN GROUND TEST?

Testing of BBM



WHAT CAN WE VERIFY IN GROUND TEST?

Testing of BBM of each component

- ➢ If each component works well and we know about each component enough, we can resolve problems of the satellite BBM more easily.
- ➢ I think we should take time for test of each component and BBM in the development of nano/pico satellite.

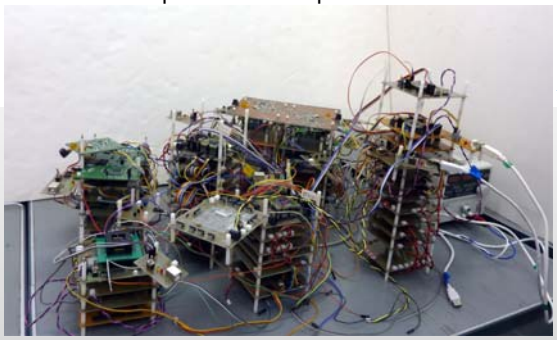
No.	Typical Test	Evaluation
1	Functional test including each specific test	Basic design and analysis
2	Thermal test	Temperature characteristics
3	Vacuum test (Outgas test)	Performance under vacuum
4	Vibration test (Shock test)	Tolerance for launch environment
5	Radiation test	Tolerance for total doze and single event (if possible)

We can feel that each component (subsystem) probably works well in space after the experience of launch load.

WHAT CAN WE VERIFY IN GROUND TEST?

Testing of integrated BBM

- ➢ Functional test of each component by using the integrated BBM
- ➢ Operation test of the integrated BBM based on mission sequence.
- ➢ I think the operation test of BBM is one of the most important test in the development of nano/pico satellite.

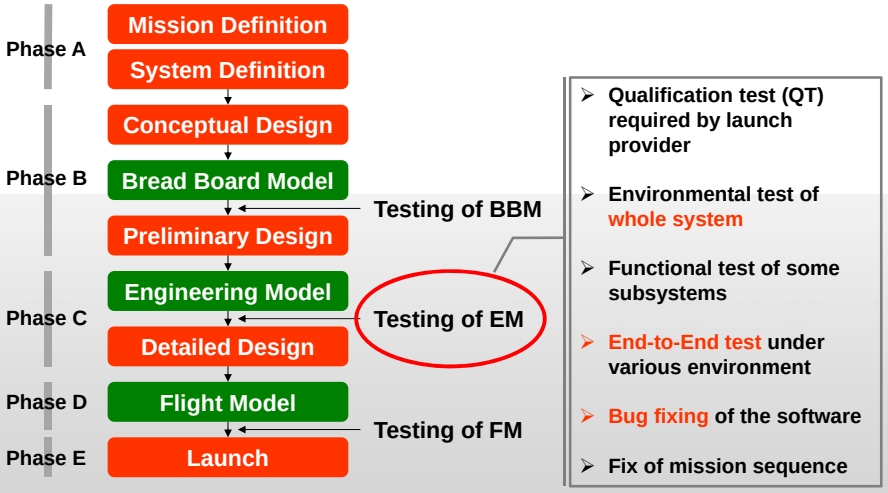


← **BBM of SPROUT**

You never make such a messy BBM…

After we overcome the "first barrier", we can feel that the system probably works well electrically.

Example of Design Process



Typical Environmental Testing of EM

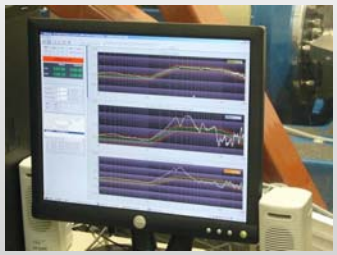
- Testing to verify the satellite system

No.	Typical Testing	Evaluation
1	Vibration test (Structural and Thermal Model, STM)	Tolerance for launch environment
2	Shock test (STM)	Tolerance for launch environment
3	Thermal vacuum test (STM)	➢ Thermal balance ➢ Functional testing under vacuum and specific temperature cycle ➢ Correlation with thermal analysis
	(Thermal test)	Temperature characteristics of satellite system (e.g. power generation, consumption, battery charge, etc.)
	(Vacuum test)	Functional testing under vacuum

Typical Environmental Testing of EM

❖ **Vibration test**

Facility	Vibration exciter
Simulation	Vibration environment during launch (given by launch provider), e.g. sine-sweep, random vibration, and multi-sine inputs.
Evaluation	➢ Tolerance for the vibration ➢ Correlation with structural design (natural frequency, damping, …)



Typical Environmental Testing of EM

❖ **Vibration test**

- It is important to imagine what will occur during the launch and the operation in space.

Typical Environmental Testing of EM

❖ **Vibration test**

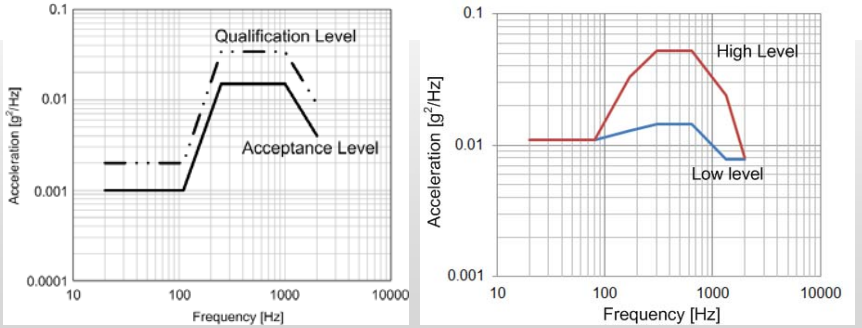
- Modal survey to detect natural frequency
- Sine burst test to verify the tolerance to the quasi-static acceleration
- Sine sweep test to verify the tolerance to the launch vibration
- Random vibration test to verify the tolerance to the launch vibration and to estimate the amplitude of load acceleration

Test Item	Verification	Requirement/ test condition
Modal survey	Natural frequency	Requirement: >100Hz Test: 20-2000Hz,0.5G,2oct/min
Sine burst	Static load	Rocket axis direction: -7G～+6G, Normal direction: -6 G～+6G（2 sec）
Sine sweep	Sine vibration	Rocket axis: 5-100Hz, 3.0G0-p, Normal: 5-100Hz, 2.0G0-p, Up/Down sweep（2 oct/min）
Random	Random vibration	20～200Hz：+3dB/oct, 200～2000Hz：0.03G^2/Hz, Effective value: 11.0Grms

Typical Environmental Testing of EM

❖ **Vibration test**

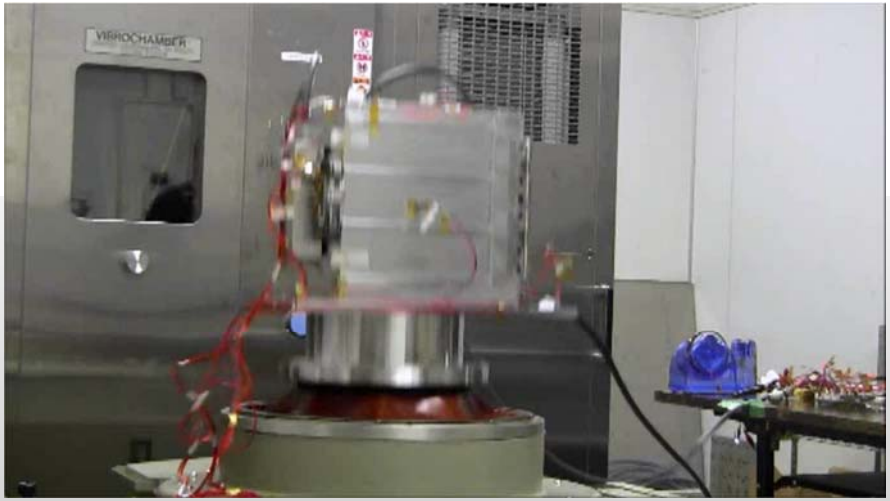
- Modal survey to detect natural frequency
- Sine burst test to verify the tolerance to the quasi-static acceleration
- Sine sweep test to verify the tolerance to the launch vibration
- Random vibration test to verify the tolerance to the launch vibration and to estimate the amplitude of load acceleration



Example of random vibration test level

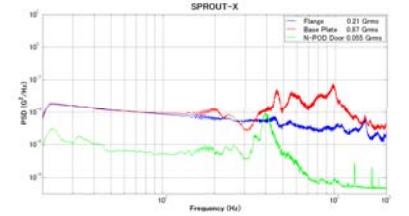
Typical Environmental Testing of EM

❖ **Vibration test**

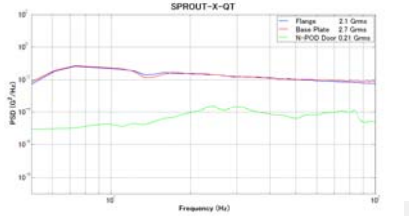


Typical Environmental Testing of EM

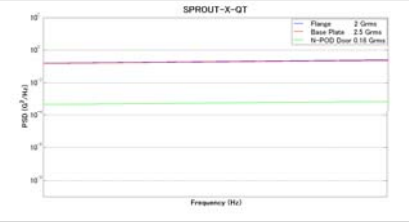
❖ **Vibration test**



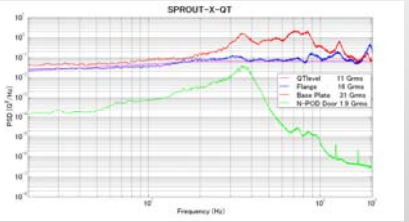
Modal survey



Sine sweep



Sine burst



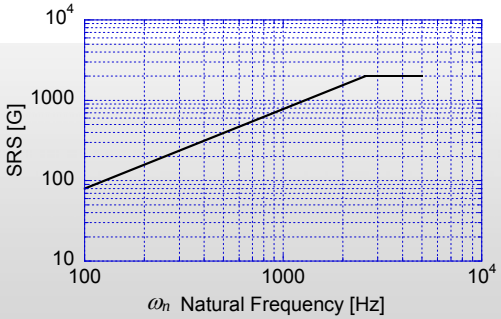
Random

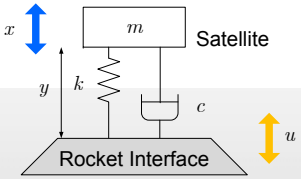
Typical Environmental Testing of EM

- **Shock test**

  To verify tolerance to shock at separation of rocket fairing and at separation of satellite

  - SRS (Shock Response Spectrum) should be larger than that given by rocket provider.





$$x = y + u$$

$$m\ddot{x} + c\dot{y} + ky = 0$$

$$\Rightarrow \quad \ddot{y} + 2\zeta\omega_n\dot{y} + \omega_n{}^2 y = -\ddot{u}$$

$$SRS = SRS(\omega_n) = \max(|\ddot{y} + \ddot{u}|)$$

ζ : given by rocket provider

Typical Environmental Testing of EM

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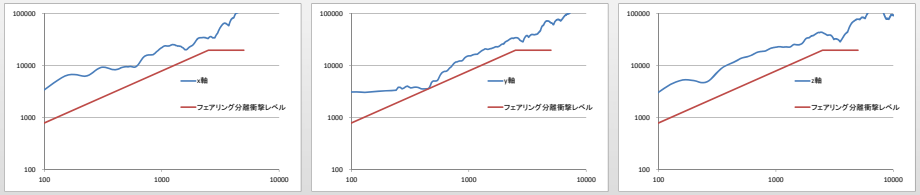
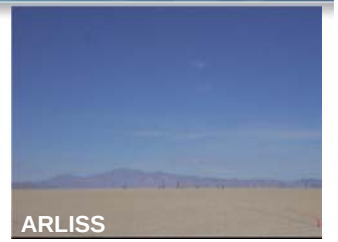


Red: required value
Blue: test result

In case of CanSat

It is important to imagine what will occur during the flight

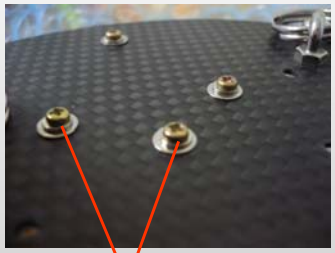


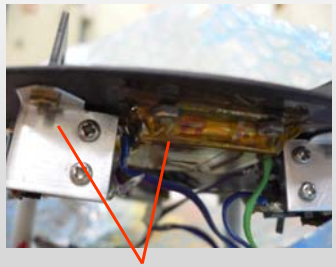
Rocket experiment at Futawa field

Balloon experiment at Futawa field

In case of CanSat

- **Vibration test**
  - ✓ Not necessary for balloon experiment
  - ✓ Sine-sweep and random (for ARLISS)
  - ✓ If you do not have the exciter, you should consider the material strength and the slack at the connecter (screws, bolts and nuts)





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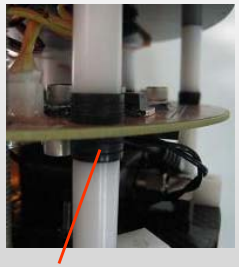
  - ✓ Sine-sweep and random (for ARLISS)
  - ✓ If you do not have the exciter, you should consider the material strength and the slack at the connecter (screws, bolts and nuts)

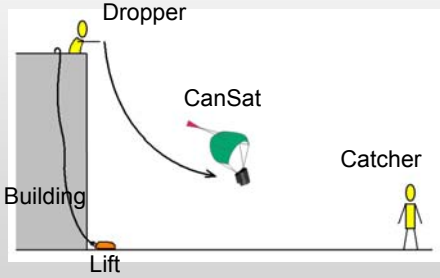


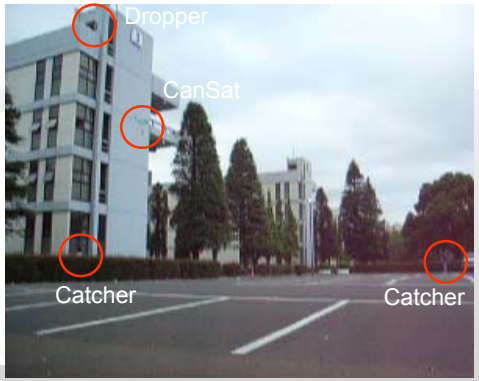
In case of CanSat

- **Shock test**
  - ✓ We should consider test method to simulate the shock at the deployment from the rocket
  - ✓ Example: hanging the parachute and dropping the CanSat with appropriate weight
  - ✓ Strength of parachute cables, connection ring, and top plate should be verified.

In case of CanSat

- **Drop test**
  - ✓ To verify smooth deployment of parachute or parafoil
  - ✓ The folding pattern gives great influence on the deployment.
  - ✓ We can obtain the best method to fold by this testing.





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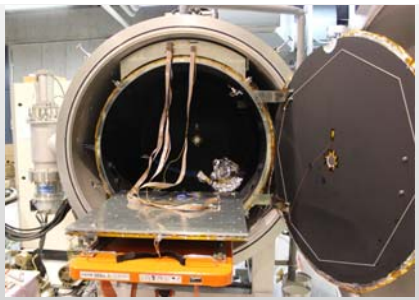
Typical Environmental Testing of EM

- **Thermal vacuum test**

Facility	Thermal vacuum chamber
Simulation	Space environment (vacuum and specific temperature)
Evaluation	Function under vacuum and specific temperature cycle



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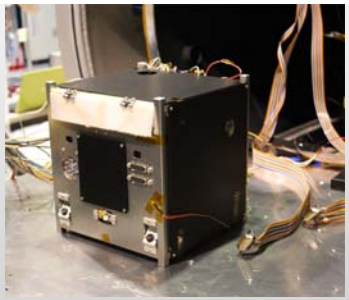

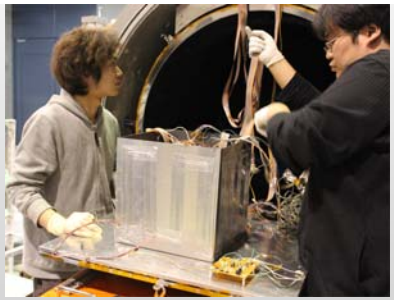

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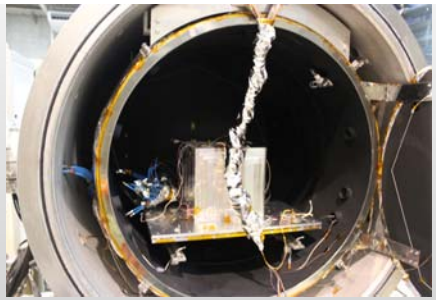

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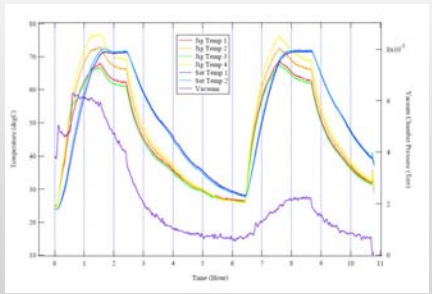

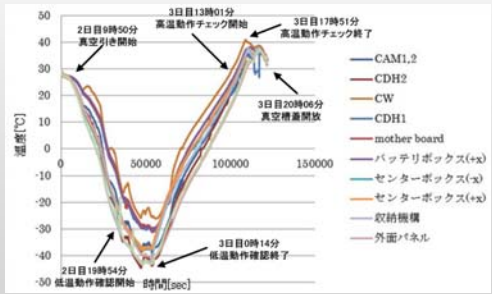

Typical Environmental Testing of EM

❖ **Thermal test**

I think the thermal test should be conducted before the thermal vacuum test to avoid the trouble in the thermal vacuum test.

Facility	Temperature-humidity chamber
Simulation	Temperature (typically from -40 or -30deg to +60 or +80deg, which depends on thermal analysis)
Evaluation	Temperature characteristics of satellite system

Typical Environmental Testing of EM

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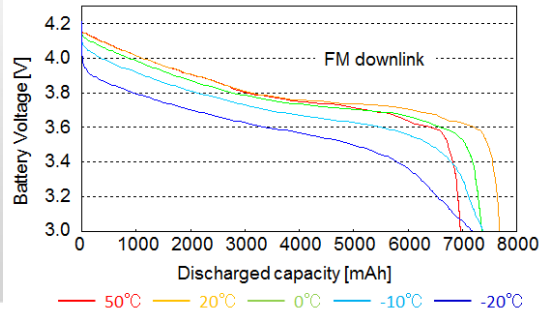
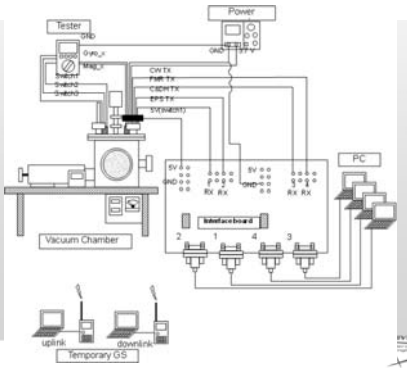


Typical Environmental Testing of EM

❖ **Vacuum test**

I think the vacuum test should be conducted before the thermal vacuum test to avoid the trouble in the thermal vacuum test.

Facility	Vacuum chamber
Simulation	Vacuum environment
Evaluation	Function under vacuum, Initial outgas



Typical Functional Testing of EM

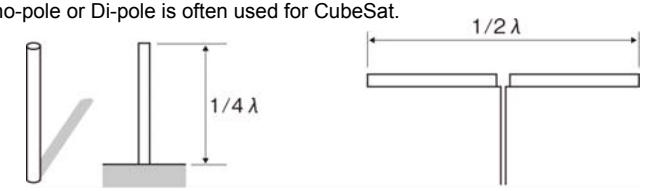
We should verify the function of each component after integrated into the satellite system. If the testing is not possible, we should evaluate it by theoretical (numerical) investigation. We can decide what test we do.

No.	Typical Testing	Evaluation
1	Functional testing based on mission sequence (before and after environmental testing)	All functions of the satellite
2	Antenna testing (STM)	Antenna pattern, Impedance matching
3	Electro-Magnetic Compatibility testing	Electromagnetic compatibility between components

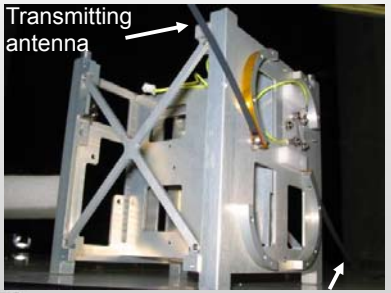
Typical Functional Testing of EM

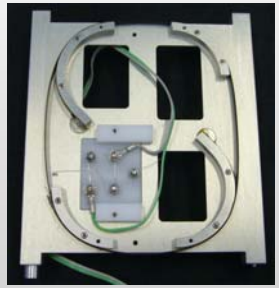
- **Antenna test**

Mono-pole or Di-pole is often used for CubeSat.



The satellite structure is the ground





Receiving antenna

Typical Functional Testing of EM

- **Antenna test**

Facility	Spectrum analyzer, Network analyzer
Evaluation	Antenna pattern and impedance matching of antenna with satellite structure

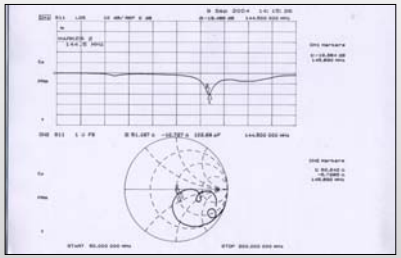
Impedance matching

Typical Functional Testing of EM

- **Antenna test**

Facility	Spectrum analyzer, Network analyzer
Evaluation	Antenna pattern and impedance matching of antenna with satellite structure

- Impedance matching is quite important.
- Voltage Standing Wave Ratio (VSWR) should be near 1 (return loss should be 0).
- The antenna length should be adjusted so VSWR is small.



SEEDS-I: 207mm
SEEDS-II: 215mm
(theory:172mm)

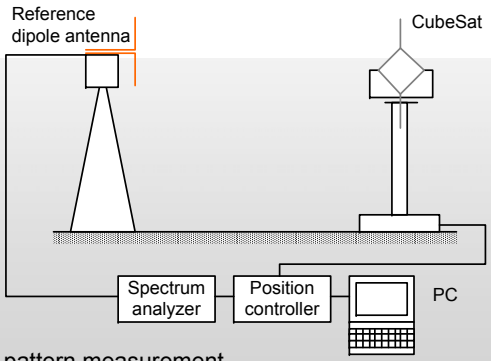
Impedance matching

Typical Functional Testing of EM

❖ **Antenna test**

Facility	Spectrum analyzer, Network analyzer
Evaluation	Antenna pattern and impedance matching of antenna with satellite structure

RF shield room



Antenna pattern measurement

Typical Functional Testing of EM

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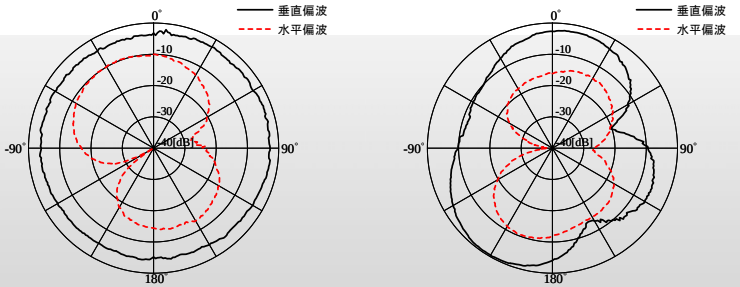

Antenna pattern measurement

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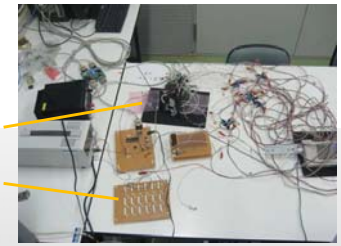
We will feel that the system (probably) works well in space.

Operational Testing of EM

- Long term test (several days or several weeks) considering day and night of the orbit (and the temperature if possible)
- All operational modes should be examined, especially emergency mode
- Housekeeping data should be checked
- I think long term test is most important.



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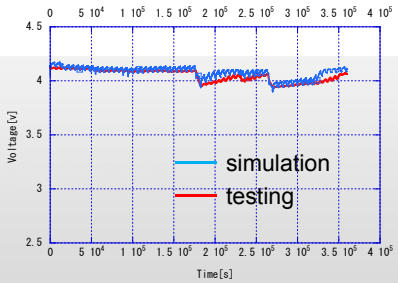
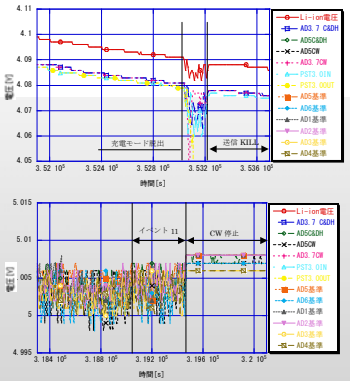


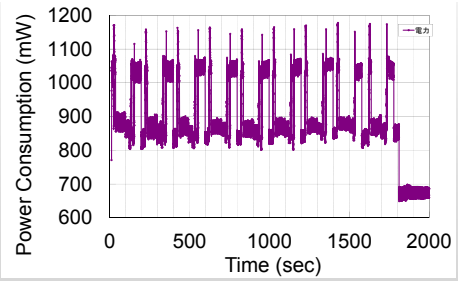
Example of test result

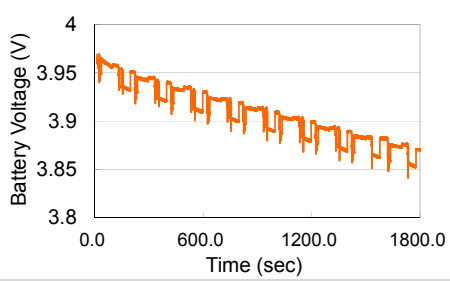


We will confirm that the satellite can survive in space.

In case of CanSat

- **Electric power test**
  - ✓ In case of CanSat, the electric power is not charged during the mission, which is different from satellites.
  - ✓ Therefore, the power budget design should be verified by testing.





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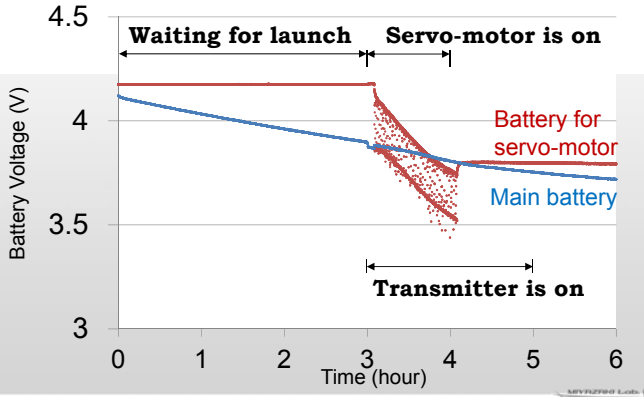
Comeback CanSat



In case of CanSat

- **Communication test**
  - ✓ To verify RF communication by measuring the decode ratio

WHAT CAN WE VERIFY IN GROUND TEST?

In case of CanSat

R: Rocket
B: Balloon

A: Analysis
T: Test

Verification		Flight		Method	
Item	Contents	R	B	A	T
Launch environment	Tolerant to acceleration load (no permanent deformation, fracture, buckling)	✓	–	✓	✓
	Tolerant to vibration (same as above, screw loose, unlatch)	✓	–	✓	✓
	Tolerant to separation shock (same as above)	✓	✓	✓	✓
	Appropriate sequence of power activation)	✓	✓		✓
Flight environment	Smooth deployment without tangling of parachute	✓	✓		✓
	Stable flight with appropriate attitude	✓	✓		✓
	Appropriate falling velocity	✓	✓		✓
Power supply	Sufficient power during mission	✓	✓		✓
Communication	Enough link budget under assumed flight environment	✓	✓		✓
Operation	End-to-end operation of system as designed	✓	✓		✓

WHAT CAN WE VERIFY IN GROUND TEST?

What should we consider?

- ✓ We should determine the requirement for each component, subsystem, and whole system at first.
- ✓ We should consider the margin for test level.
- ✓ **If the preliminary consideration (design and analysis) is poor, we cannot get good feedback from the test result.**
- ✓ Testing is closely related to the reliability of the satellite (The reliability of the satellite is determined not only by the design and fabrication, but also by the testing).
- ✓ We should consider the performance and reliability of the satellite, the cost and schedule to develop the satellite. But the performance, reliability, cost and schedule conflict with each other.
- ✓ If we come to believe before launch that our satellite will surely achieve the mission success, we conducted the best test.

WHAT CAN WE FEEDBACK TEST RESULTS?

Feedback from test results of EM to fabrication of FM

It's very simple!

- ➢ If we have no trouble with the test, our design and development is probably enough.
- ➢ If we have some trouble, we should detect the exact cause of the trouble and fix it.

But,

- ➢ Sometimes it is not easy to detect it and we may be misled by the visible phenomenon…
- ➢ Sometimes we cannot take the best measure for the trouble because of the cost or schedule.

Therefore, .

- ➢ We should always have appropriate margin for satellite (weight, layout, cost, schedule, and so on)

WHAT CAN WE FEEDBACK TEST RESULTS?

Feedback from test results of EM to fabrication of FM

Example;

- ➢ After vibration test,

Trouble	Feedback
Unexpected plastic deformation (insufficient material strength)	The design (diameter, length, layout, topology, …) should be changed or the more damping should be given.
Unexpected slack (loosen of screws)	➢ The tightening torque should be controlled. ➢ The lock tight® should be applied to the bolts.
The hinges of the deployable structure (e.g. solar panels) are locked.	➢ The strength of the hinges may be insufficient. ➢ The clearance gap may be too small. ➢ The surface coating may be applied.
The resonance peak at some part is too high.	➢ The damping material should be installed at the bolts, or between the parts, or between the satellite and the base, or …

Feedback from test results of EM to fabrication of FM

Example;

- After vacuum test,

Trouble	Feedback
Outgas	The material should be re-considered.
Burst, air leak, …	➢ The shield should be more tight. ➢ The parts available in vacuum should be used.

- After thermal-vacuum test,

Trouble	Feedback
Heat spot	➢ The layout may be changed. ➢ Some heat storage material may be available.
Insufficient correlation with numerical analysis	➢ The thermal analysis model should be changed (finite element, heat conductivity, …)
Low temperature	➢ A heater circuit may be installed if the power budget has some margin.

Feedback from test results of EM to fabrication of FM

Example;

- After operational test,

Trouble	Feedback
Noise	➢ The layout may be changed. ➢ The appropriate filter circuit may be implemented. ➢ The electromagnetic shield film may be a little effective.
Hang-up, Delay of processing, …	We can detect the bugs (software or hardware) only by logical investigation.
Large power consumption	➢ The prediction (calculation) of the power consumption may be not good. ➢ Power leak? (dangerous) ➢ If there is no bug, we should avoid the power shortage by well-considered operation.
Maintenance	The layout or integration process may be changed.

Long-term operational testing is quite good chance to get the tips for improvement (bug-fix) of the satellite system.

Testing of Flight Model

Purpose;

- Final verification (confirmation) of our design and fabrication
- Evaluation for readiness to launch (acceptance test)
- We should deeply consider the risk to modify the flight model after the testing (Sometimes, even a little modification causes the critical failure).
- If something happened in the testing of the flight model, we may re-consider the operation (sequence of the mission) to avoid the trouble.

No.	Typical Testing	Evaluation
1	Vibration testing (shock testing)	Tolerance for launch load (AT level)
2	Thermal vacuum testing	Operation in vacuum at low or high temperature
3	Thermal bake-out	Out-gassing

In Case of CanSat

What should we consider? – same as real satellite;

- At first, we consider what the CanSat will experience before the flight, during the flight, and after the flight.
- Then, we consider what we should verify to confirm that our CanSat achieve the successful result.
- Then, we make the verification plan, i.e. what testing and what analysis we conduct.
- We should conduct all kinds of testing in order to achieve the mission success in our own situation.
- I think that the discussion between members is most important to determine what testing we should do.

In this lecture, I talked about

1. Purpose of the testing for BBM, EM, and FM of nano/pico satellite
2. Type of testing (environmental testing and operation testing)
3. Example of testing (vibration, thermal vacuum, thermal, vacuum, antenna characteristics, and operational testing)
4. Example of testing for CanSat (vibration, shock, electric power, parachute deployment, communication, and balloon testing)

I think

- The purpose of the testing is to assure the performance and the reliability of the system combined with theoretical (numerical) analysis, i.e. to reduce the risk of mission failure as low as reasonably practical (ALRP) under some uncertainty and restriction of the cost and schedule (development time).
- We should imagine the whole life of the satellite (from the delivery to the launch provider to the shut-down in space), and conduct the test to confirm that our satellite works well during the mission.
- If we do not verify something, the failure (problem) will surely occur due to it.
- We should conduct all kinds of testing that we can in our own situation in order to achieve the mission success.