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Lab #6 Structure Subsystem

Structure Design/Analysis/Environment test

In this session, the Structure subsystem(STR) of a typical CubeSat will be explained and participants will experience the actual assembly, integration and testing of the Structure subsystem using HEPTA-Sat.

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1. **What is Structure Subsystem?**
   a. Understand roles and functions
   b. Understand the physical structure (system diagram)
2. **How to design Structure Subsystem**
   c. Understand design of Structure subsystem
3. **Assembly, Integration and Test**
   d. Understand how components are integrated and tested
   e. Experience assembly, integration, and test (AI&T)
4. **Appendix**

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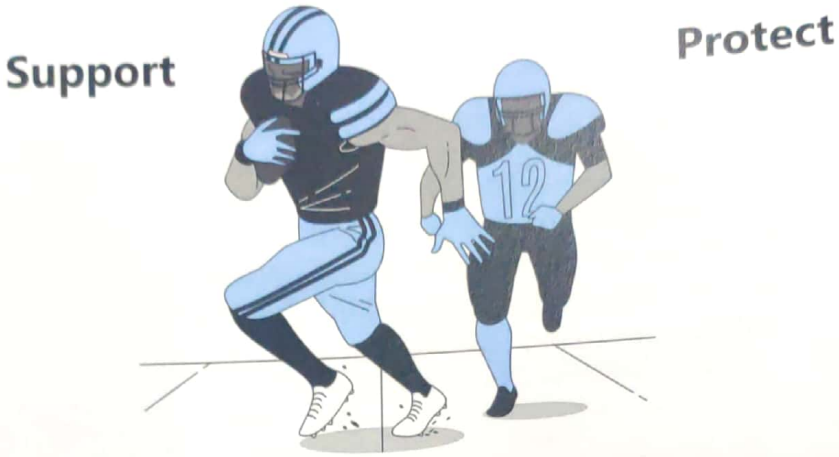
1.1 Role

- What is the role of Structure Subsystem?
- In humans, the structural system is made up of the body itself, including the skeleton, muscles, and skin.



- The human body, including the skeleton, muscles, and skin, can support the body, protect its internal organs from external shocks, and alter its structure by moving its arms and legs.
- And the surface of the body is equipped with various functions such as pores for air intake, and holes for food intake.

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1.1 Role

- Similarly, satellites have two roles: to protect the internal equipment so that it can withstand launch and the space environment, and to support the internal equipment so that it can function.
- For example, for a satellite to function properly in orbit, it must be able to withstand vibration and shock during launch and the orbital environment. In addition, the relationship between onboard instruments may be kept constant by the structure, or the structure may become part of the observation equipment.

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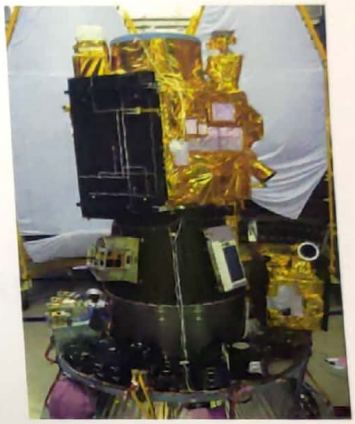
1.2 Requirement Managing Mechanical Interface

- CubeSats are generally mounted and launched on a rocket. Most CubeSats are launched by piggybacking on the surplus space available when launching large satellites.
- A POD(Picosatellite Orbit Deployer) is mounted on the rocket, and the satellite is stored in the POD. When it is time for release, an electrical signal is sent to the CubeSat deployer, the door opens, and the CubeSat is released into orbit.
- Therefore, the size of the satellite is limited and the power supply is turned off (cold launch) during launch so as not to affect the main satellite. A physical switch (release detection switch) is required to detect the release, which turns the power ON after the satellite is released into orbit.



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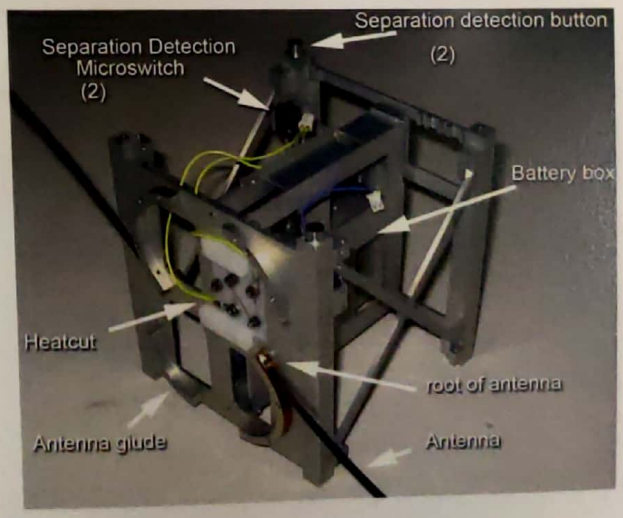
1.2 Requirement Managing Mechanical Interface

- In addition, the onboard equipment is secured to the structure in some form and transported into space. There are also deployed parts (antennas, etc.) which separate from the structure in space, but most parts are secured to the satellite structure, and are used while the positional relationship is retained (solar cells, sensors, actuators, etc.)



1U CubeSat SEEDS-II (©Nihon University)

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1.2 Requirement Withstanding launch and orbit environment

- A design capable of withstanding vibrations, loads, and shocks while being transported into space is required.
- The system must also be protected so that it can continue to function normally during the mission in harsh environments, such as exposure to radiation or heat, and in a vacuum, even after entering orbit.

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1.3 Wrap up of Structure subsystem

- This is a summary of roles, functions and physical elements.

- Role -

To mediate the interface with the outside to protect the satellite from launch and the orbital environment

- Function & Physical -

Functional Requirements	Physical Elements
Managing Mechanical Interface	Structure, Release detection switch, RBF Pin
Withstanding launch and orbit environment	Structure

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1. What is Structure Subsystem?
   a. Understand roles and functions
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2. How to design Structure Subsystem
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4. Appendix

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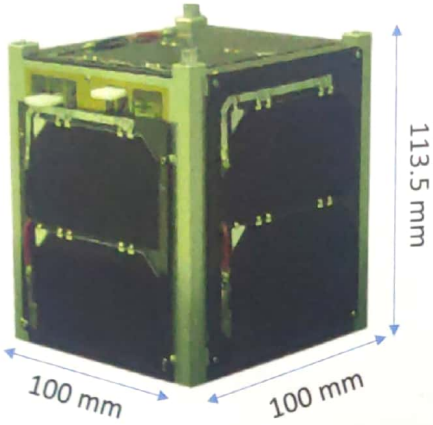
2.1 Overview of design process

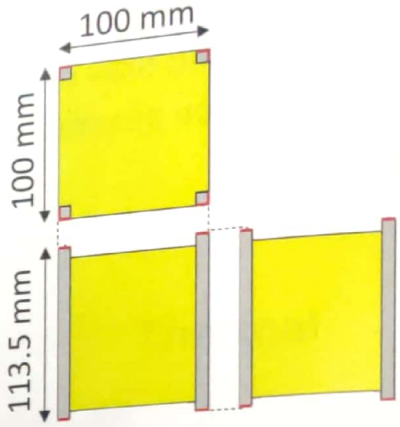
- The Structure subsystem design process involves coming up with a structural design, arranging the components, designing deployed structures, and conducting strength analysis and thermal analysis to satisfy the rocket requirements.

2.2 Hardware design Managing Mechanical Interface

- **CubeSat standard (shape, size, and weight)**
  - A CubeSat, must conform to specific criteria that control factors such as its **shape, size, and weight**.
    - **This affects resources such as size and power available for payloads.**
  - The specific standards for CubeSats help reduce costs.
  - A 1U CubeSat is a 10 cm cube with a mass of approximately 1 to 1.33 kg.



1U CubeSat SEEDS-II © Nihon University



1 Unit: 10 cm cube, 1.33kg

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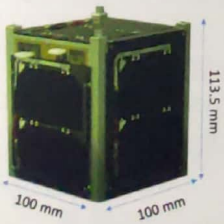
2.2 Hardware design Managing Mechanical Interface

- **CubeSat standard (shape, size, and weight)**
  - CubeSats come in several sizes, which are based on the **standard CubeSat unit (called 1U).**



1U CubeSat SEEDS-II
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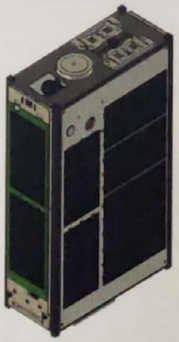

W6U CubeSat Prelude
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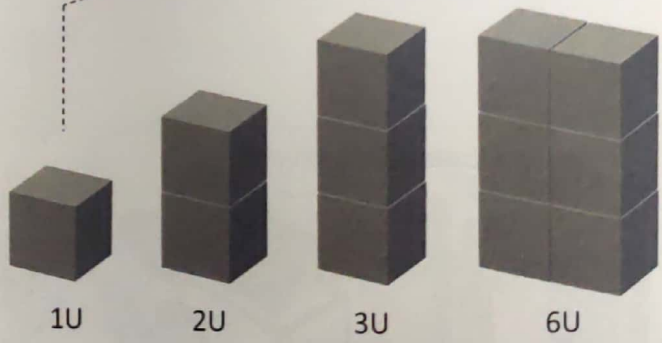

Standard sizes of CubeSat

CubeSat Design Specification rev.13 (2014/2/20)
6U CubeSat Design Specification rev. 1.0 (2018/6/7) - California Polytechnic State University
(https://www.cubesat.org/)

JEM* Payload Accommodation Handbook Vol.8 D - JAXA (* Japanese Experiment Module (JEM) = Kibo)
(https://iss.jaxa.jp/kibouser/provide/j-ssod/#sw-library)
(https://humans-in-space.jaxa.jp/kibouser/library/item/jx-espc_8d-d1_en.pdf)

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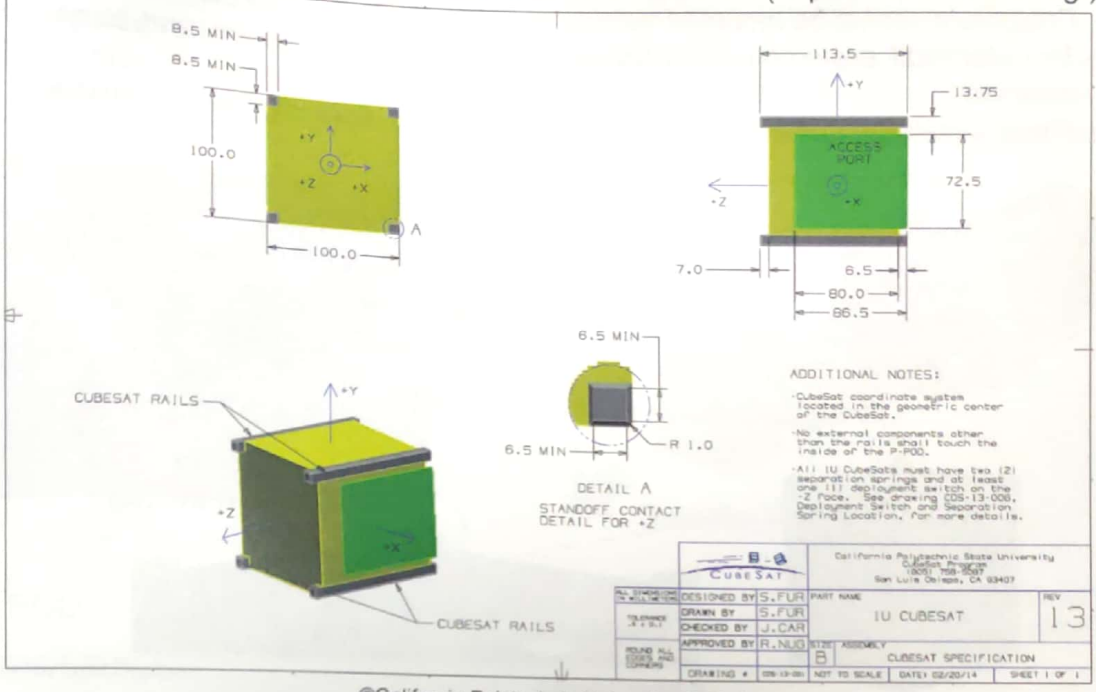
2.2 Hardware design Managing Mechanical Interface

- **CubeSat standard (shape, size, and weight)**
  - For example, California Polytechnic University (CalPoly) has set and published external dimension standards for PODs and satellites.(http://www.cubesat.org/)



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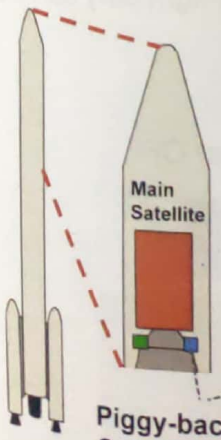
2.2 Hardware design Managing Mechanical Interface

- **CubeSat Orbit Deployer**
  - The deployer is the **interface between the CubeSat and the launch vehicle**.
  - The deployer is attached to launch vehicle, releases it into space at the appropriate time.
  - When it is time for release, an electrical signal is sent to the CubeSat deployer, the door opens, and the CubeSat is released into orbit.



Piggy-back satellite with CubeSat Orbit Deployer

CubeSat Orbit Deployer(Jack-in-the-box)

Inside of Launch vehicle

The CubeSat orbit deployer is designed to meet the CubeSat standard.

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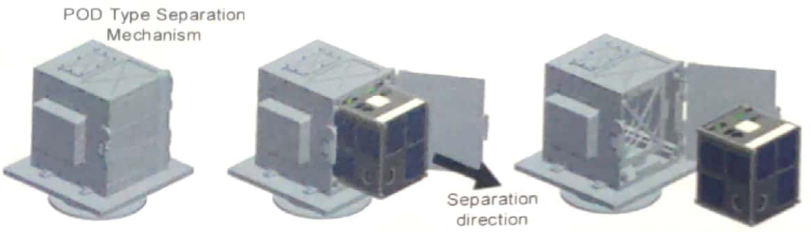
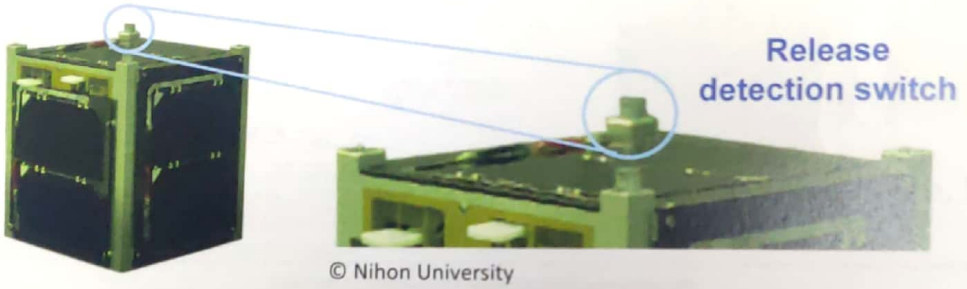
2.2 Hardware design Managing Mechanical Interface

- **CubeSat Orbit Deployer**
  - A CubeSat, must conform to specific criteria that control factors such as its shape, size, and weight.
  - Equipment cannot be mounted outside of the CubeSat orbit deployer envelope.
  - The electrical power must be turned off before orbit insertion and turned on after insertion.
  - These constraint affects the size, weight, shape and operation of the payload.



CubeSat Orbit Deployer(Jack-in-the-box)



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Lab#6 > 2. How to design STR subsystem

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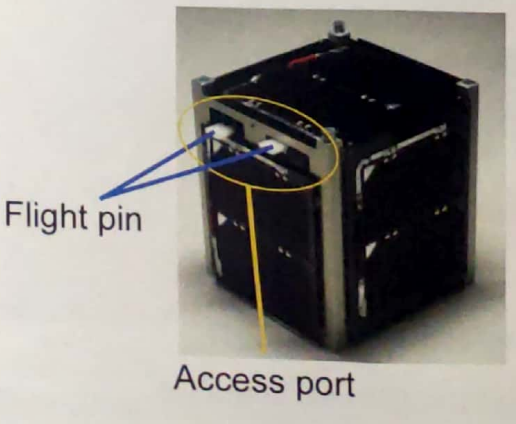
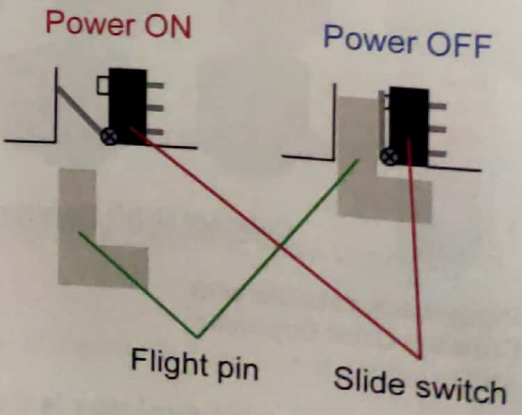
2.2 Hardware design Managing Mechanical Interface

- **CubeSat Orbit Deployer**
  - The CubeSat orbit deployer (POD) may have a window (access port) that can be accessed from the outside of POD. After the satellite structure has been assembled, it may be desirable to perform detailed signal and operation checks. For this purpose, electrical connection pins to the inside of the satellite are designed on the satellite surface corresponding to the access port portion of the POD so that charging and operation checks can be performed.
  - In addition, physical pins called flight pins (RBF pin: Remove Before Flight pin) can be inserted to control the ON/OFF of the satellite's power supply.





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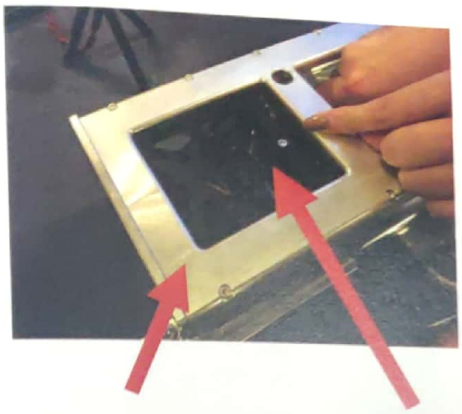
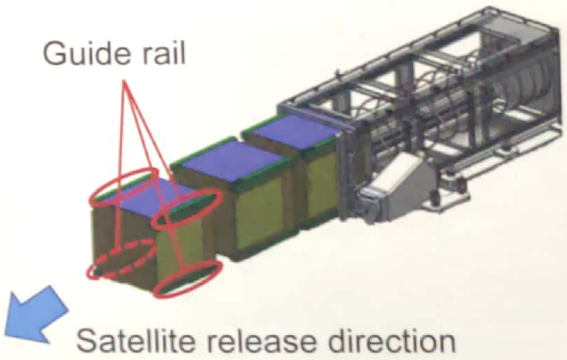
2.2 Hardware design Managing Mechanical Interface

- **CubeSat Orbit Deployer**
  - The satellite is stored in a POD before launch and the satellite access port and the POD access port must be aligned so that the satellite system can be accessed from outside the POD.
  - A **guide rail** must also be installed to ensure release from the POD after launch. Since the size and position of the rails have been established in detail, the design process should be carried out while carefully reading the requirements for the launch side.





Reference: JEM Payload Accommodation Handbook Vol. 8 D
https://iss.jaxa.jp/kibouser/library/item/jx-espc_8d.pdf

* POD: Picosatellite Orbit Deployer

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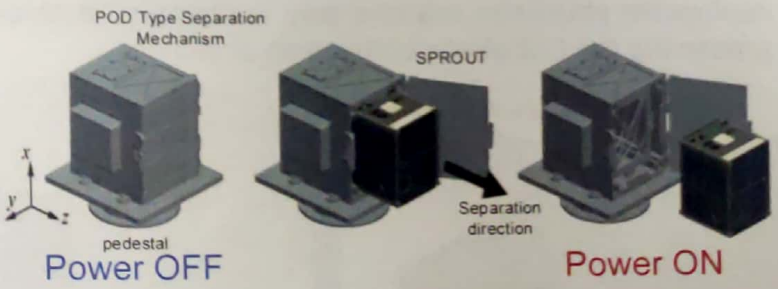
2.2 Hardware design Managing Mechanical Interface

- **CubeSat Orbit Deployer**
  - When launching with the piggyback system, the successful launch of the main satellite is of top priority, and a cold launch is required for the other satellites to minimize the impact on the main satellite. The satellite must therefore have a mechanical switch (release detection switch) that is turned OFF while in the POD, and turned ON when released from the POD.



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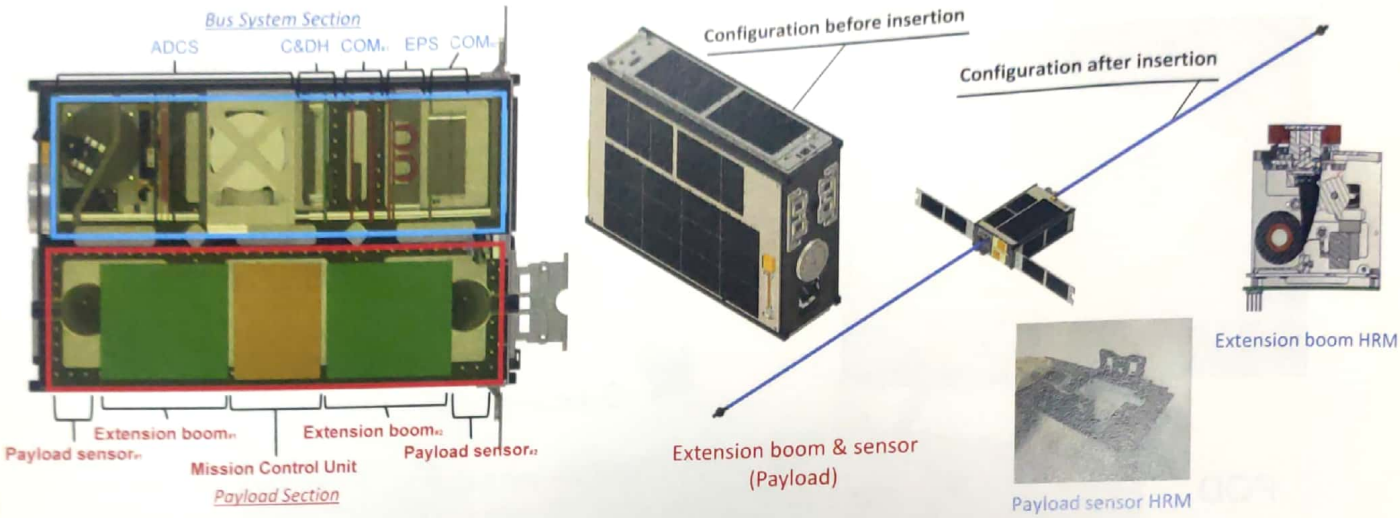
2.2 Hardware design Managing Mechanical Interface

- **Hold & Release Mechanism (HRM)**
  - The size, weight, and shape constraints affect the size, weight, and shape of the payload.
  - However, if a hold-and-release mechanism is installed, the solar panels and deployable sensors can be held before release and deployed after release into orbit, triggered by a signal from the CubeSat.



6U CubeSat Prelude © Nihon University

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Lab#6 > 2. How to design STR subsystem

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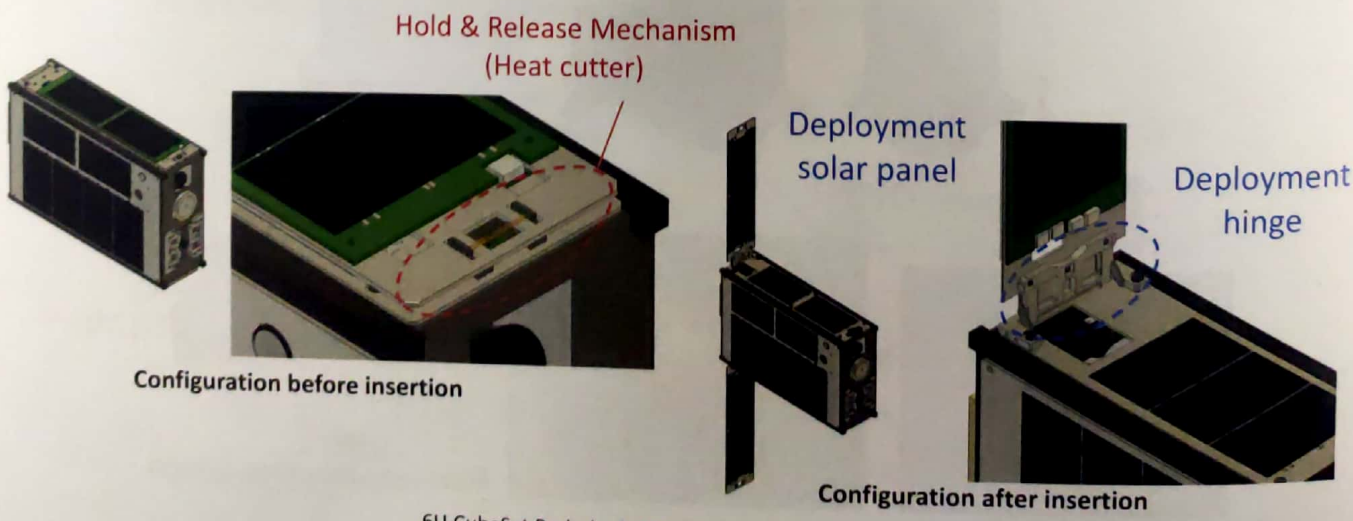
2.2 Hardware design Managing Mechanical Interface

- **Hold & Release Mechanism (HRM)**
  - Before the CubeSat is released into orbit, these deployables need to be constrained.
  - The most common method of constraint is to tie a fishing line to the component and pass the other end by a simple resistor such as nichrome wire.
  - When a current is applied to the resistor and the resistor heats up sufficiently, the fishing line melts and the expanded product is released.
  - HRM and deployable structures are one way to change the shape of a CubeSat on orbit while preserving the CubeSat's constraints at launch.



6U CubeSat Prelude © Nihon University

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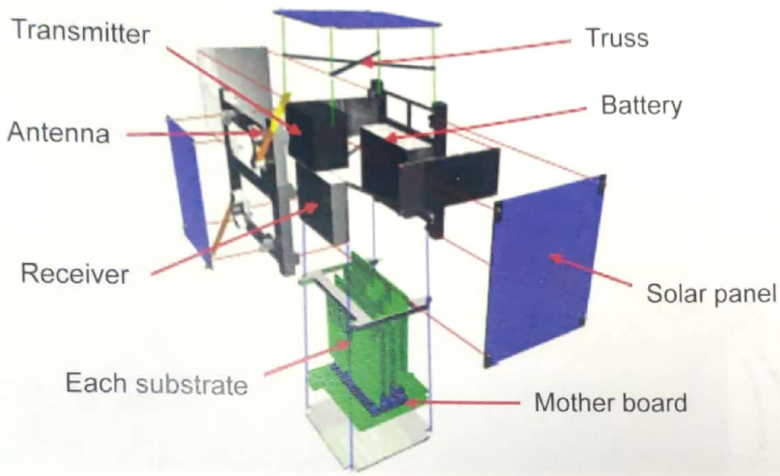
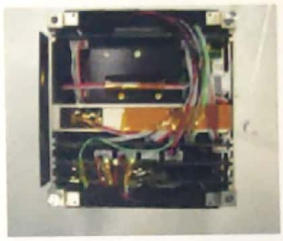
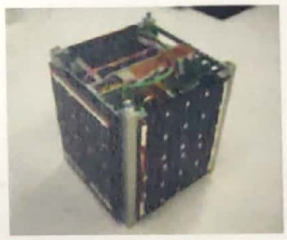
2.2 Hardware design Managing Mechanical Interface

- **Equipment layout**
  - Once the exterior has been determined to some extent, we need to consider how to position and install the components. It is also important to determine whether boards should be stacked and connected, or connected via a motherboard.
  - When considering the layout, it is necessary to consider whether components become too hot or too cold in addition to satisfying component layout restrictions. Even if unable to actively control the heat, it may be possible to rearrange the components.







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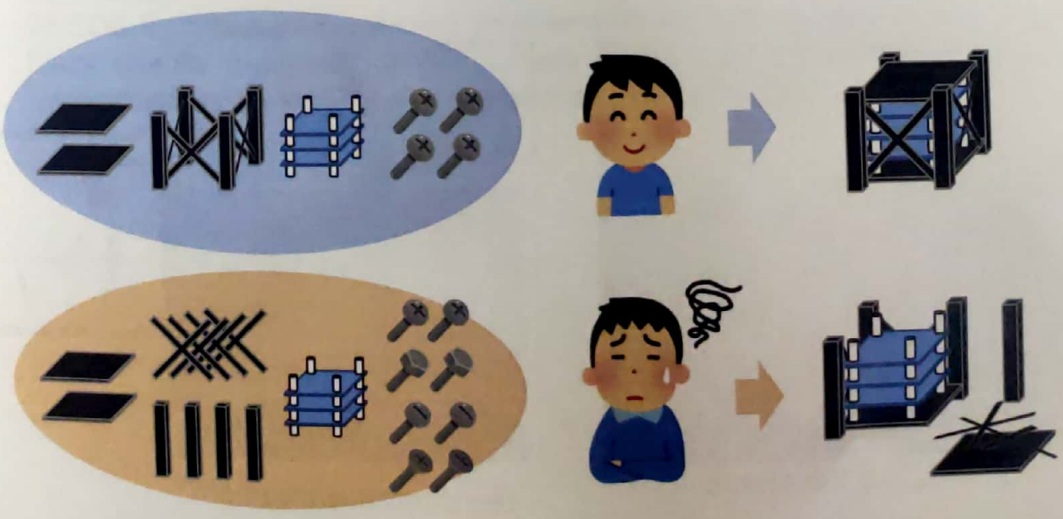
2.2 Hardware design Managing Mechanical Interface

- **Structuarl design**
  - Ease of assembly and reproducibility are key factors in designing the assembly method for satellite structures. This is because satellites can be assembled easily by anyone, and therefore it is necessary to ensure that the same accuracy is maintained no matter how many times they are assembled.
  - We need to consider how to guarantee accuracy, and whether assembly is possible with a small number of parts.



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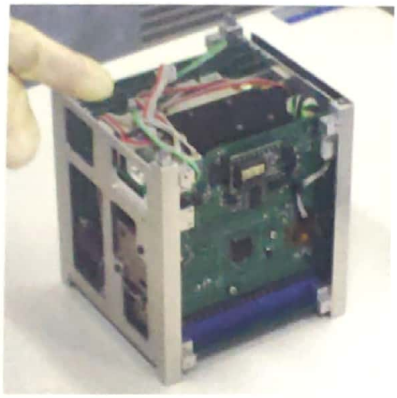
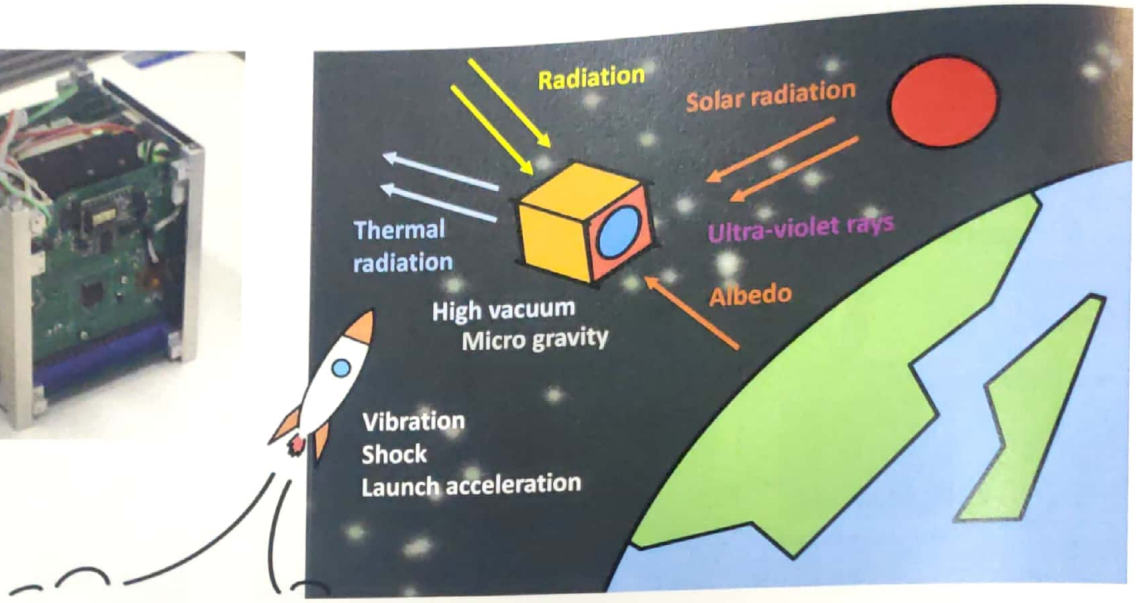
2.2 Hardware design Withstanding launch and orbital environment

- The role of the ***structural subsystem*** is to protect the satellite to withstand the launch and space environment and to support the satellite's equipment.
- The main components of the structural subsystem are panel elements and strut elements made of aluminum alloys and other materials.





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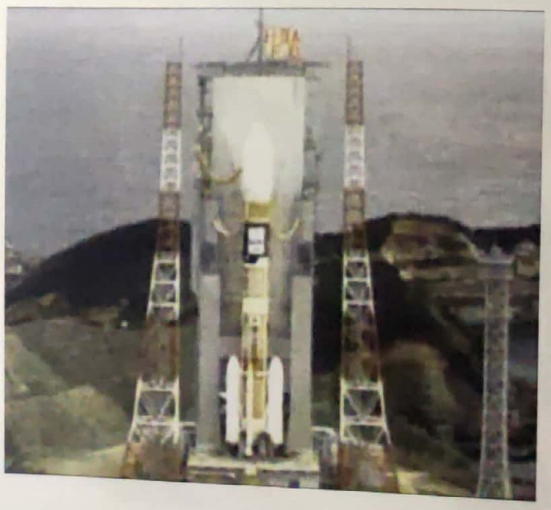
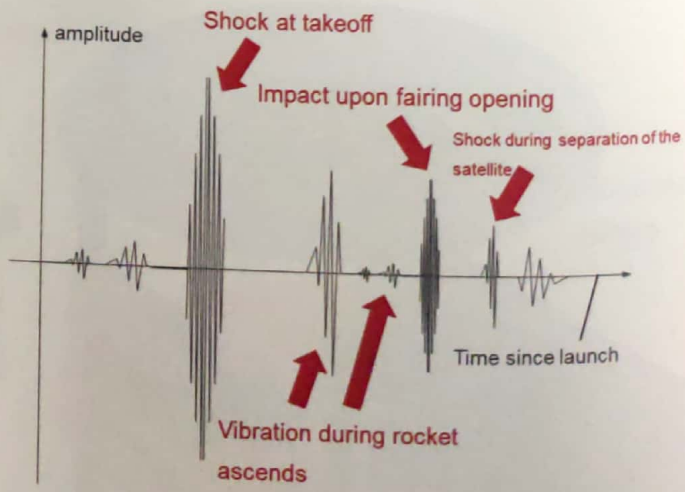
2.2 Hardware design Withstanding launch and orbital environment

- **Vibration and shock**
  - The graph on the right shows the vibration and impact load applied to the satellite during launch.
  - When launching a rocket to which vibration and impact loaded are applied, various vibration phenomena such as sinusoidal oscillation, random vibration, quasi-static acceleration, shock and sound affect the satellite. Satellites must therefore be able to withstand these loads.





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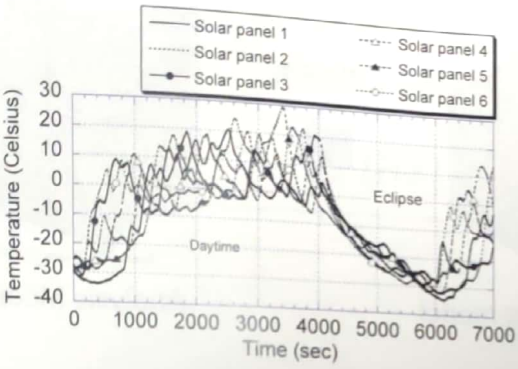
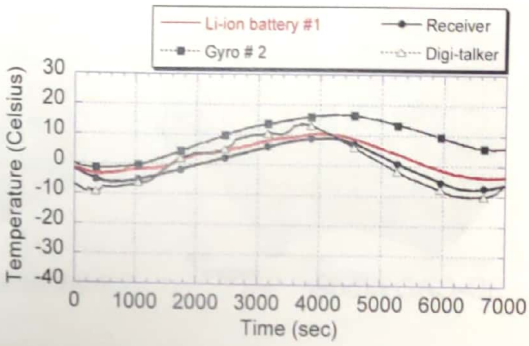
2.2 Hardware design

Withstanding launch and orbital environment

- **Thermal & Vacuum condition**
  - Satellites orbiting the Earth are affected by extreme temperature changes due to repeated exposure to sunlight and shade.
  - There is no air in space. In other words, there is no heat transfer by convection as there is on Earth. Without proper thermal design, the heat inside microsatellites may become unevenly distributed.
  - No significant uneven distribution of heat occurs with microsatellites such as CubeSat because they are able to achieve a certain extent of heat transfer through thermal conduction or radiation. However, the performance of some equipment is greatly affected by the temperature of components such as the battery. This means that we must strive to minimize temperature fluctuations for equipment with narrow operating temperature range.





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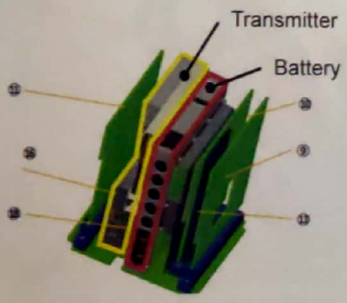
2.2 Hardware design

Withstanding launch and orbital environment

- **Thermal & Vacuum condition**
  - Thermal control includes active control using heaters, etc., and passive control without the use of any special control systems.
  - Battery performance tends to drop as temperature drops, and so it is best to locate the battery where the temperature is appropriate and is unlikely to drop. It is possible to prevent the temperature from dropping by placing it in the center of the satellite, and surrounding it with heat-generating components such as the transmitter.
  - SEEDS-II utilizes white alumite treatment on the outer panels of the satellite, and black alumite treatment on the surface of the solar panels to increase radiation inside the satellite and prevent deviations in temperature.

Thermal insulation sheet



Equipment layout

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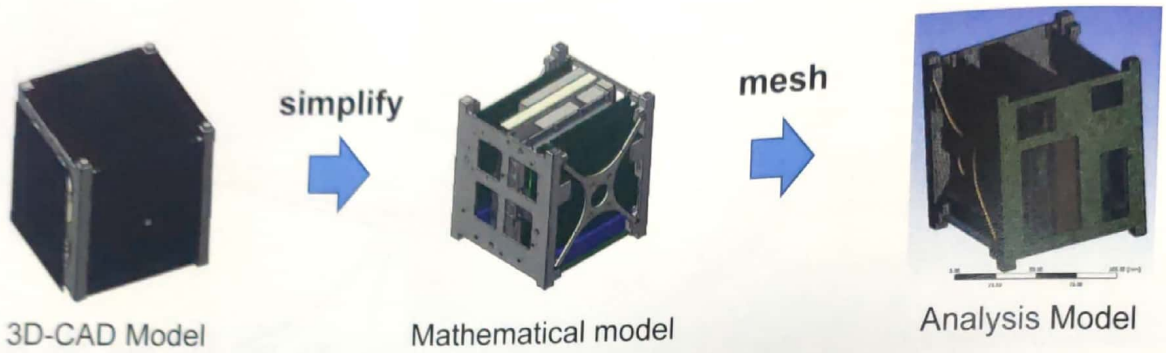
2.3 Structural Analysis Withstanding launch and orbital environment

- **Finite Element Analysis**
  - Satellites must be able to withstand the vibrations and shocks of rocket launch. It is therefore necessary to confirm through analysis that the designed structure has sufficient strength.
  - Structural analysis is used to determine the natural frequency or displacement and stress that occurs when a static load equivalent to that at launch is applied.
  - FEM(Finite Element Analysis) is a method of formulating a complex shape continuum by dividing it into simple shape finite elements and interpolating the degree of freedom of each element with the degree of freedom of the nodes.



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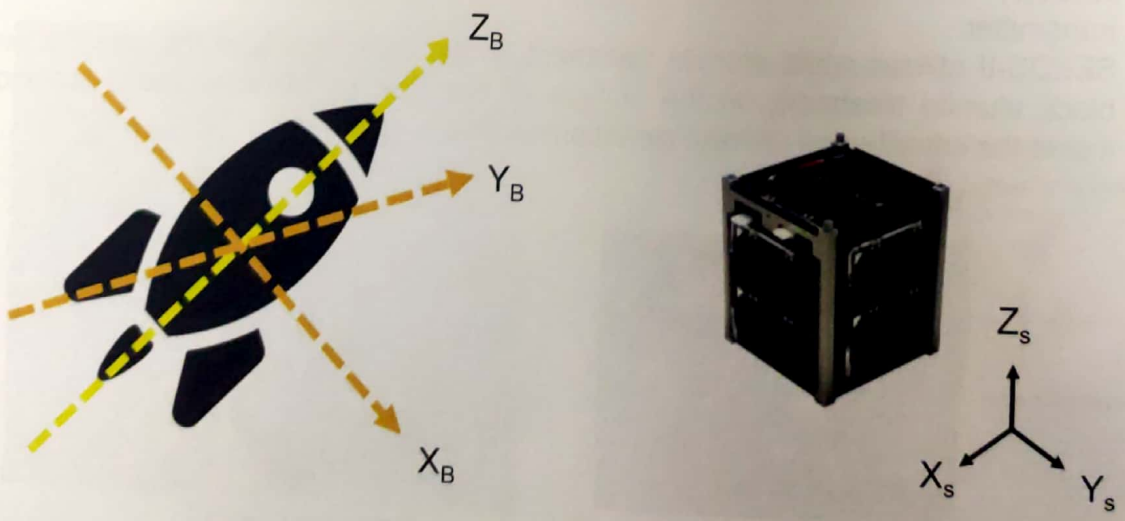
2.3 Structural Analysis Withstanding launch and orbital environment

- **Define coordinate axis**
  - To begin with, let's check the coordinate axis definition before starting analysis.
  - The following diagram is an example. In practice, the proper coordinate axes are defined based on the orientation of the satellite on the rocket.



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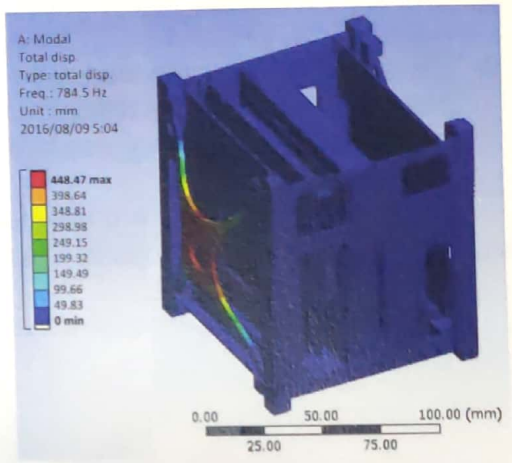
2.3 Structural Analysis

Withstanding launch and orbital environment

- **Modal analysis**
  - Resonance occurs when the vibration frequency applied to the satellite when launching the rocket is close to the natural frequency of the satellite.
  - At launch, it is necessary to ensure that the natural frequency of the satellite is greater than the dominant frequency of the rocket.

Natural Frequency		Requirement
$f_N\ [Hz]$	$>$	$f_R\ [Hz]$



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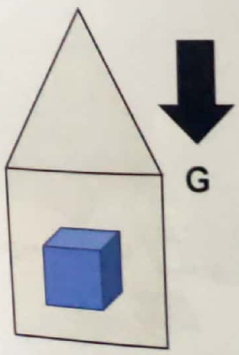
2.3 Structural Analysis

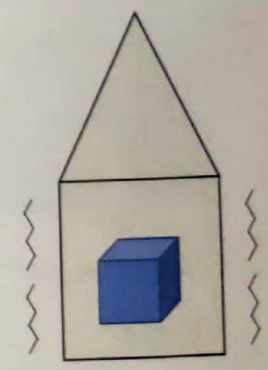
Withstanding launch and orbital environment

- **Static load analysis**
  - Analysis is carried out to determine whether the satellite is able to withstand the static load of a rocket launch.
  - The static loads to consider can be divided into the following three categories:
    - Quasi-static load (starting load)
    - Vibration load (sinusoidal oscillation)
    - Spring load (load applied with release mechanism spring)

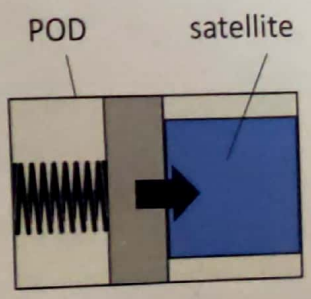
(1) Quasi-static load



(2) Vibration load



(3) Spring load



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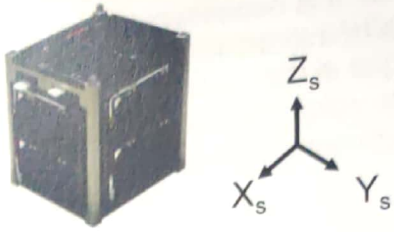
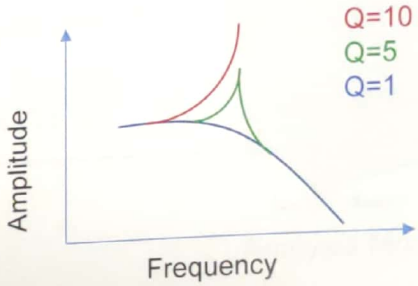
2.3 Structural Analysis Withstanding launch and orbital environment

- **Static load analysis**
  - These three loads are applied to each axis of the satellite.
  - Example:
    - Quasi-static load
      - Zs: ○ [G]
      - Xs, Ys: □ [G]
    - Spring load
      - Zs: △ [G]



- If considering vibration load, we need to substitute vibration with a load. When doing so, a response factor is typically used. This is known as the quality factor.
  - Quality factor: sharp rise in vibration response at resonance frequency
  - Vibration load
    - Xs, Ys, Zs: 1 × quality factor [G]



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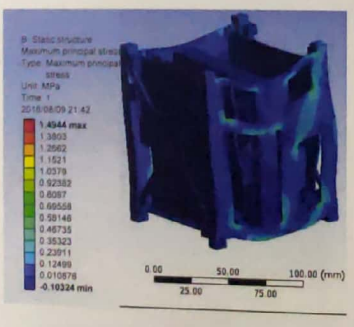
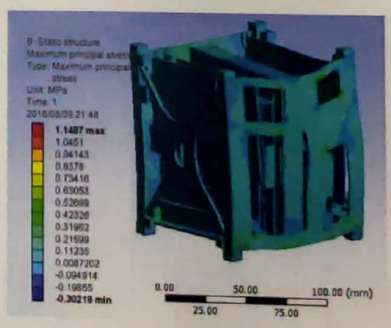
2.3 Structural Analysis Withstanding launch and orbital environment

- **Static load analysis**
  - The analysis assumes that the sum of these three loads is applied to each axis.
  - The safety margin can be calculated from the maximum principal stress and the allowable stress. If the safety margin minus 1 is positive, we can say that the load can be withstood.

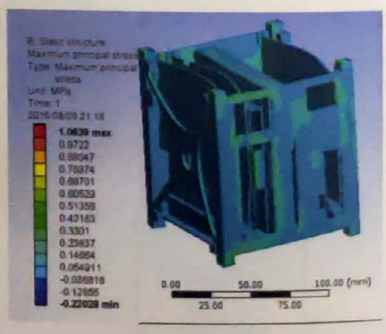
$$\text{Safety margin} = \frac{\text{Allowable stress}}{\text{Maximum stress}} - 1 > 0$$



X-axis



Y-axis



Z-axis

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2.3 Structural Analysis

Withstanding launch and orbital environment

- **Random vibration analysis**
  - It is difficult to analyze random vibrations precisely.
  - Perform static load analysis by substituting the dynamic load with a static load based on the following equation:

Miles equation

$$\ddot{x}_d = 3\ddot{x}_{rms} = \sqrt{\frac{\pi}{2} Q f_n PSD_n}$$

$\ddot{x}_d = 3\ddot{x}_{rms}$: $Acceleration$, Q : $Amplification\ ratio$
f_n : $Natural\ frequency\ [Hz]$, PSD_n : $Acceleration\ density\ [G^2/Hz]$

- Multiply the obtained static load by the factor of safety and perform static load analysis again.
- Calculate the safety margin, and ensure that it meets the standard value.

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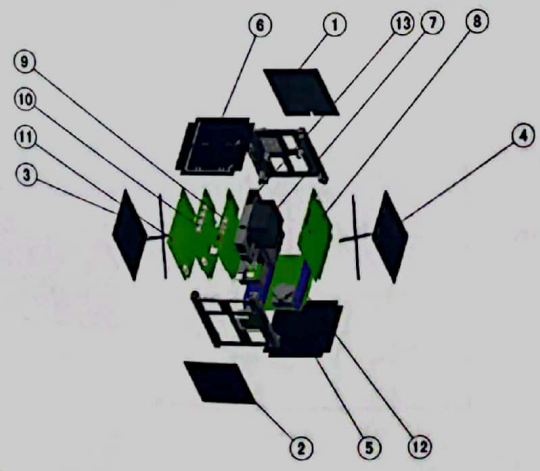
2.3 Structural Analysis

Withstanding launch and orbital environment

- **Thermal analysis**
  - A differential equation known as the thermal equilibrium equation is used to predict temperature variations both outside and inside the satellite.
  - With this method, the parts of the satellite are broken down into several parts, and the temperature variation is calculated based on the following three points:

(1) Heat is transferred between parts by thermal conduction or radiation.
(2) The power consumed by equipment is converted into a heat value.
(3) There are external thermal inputs such as sunlight and infrared radiation (albedo) reflected from earth.



No.	Element	No.	Element
1	-x panel	8	A board
2	+x panel	9	B board
3	-y panel	10	C board
4	+y panel	11	D board
5	-z panel	12	Motherboard
6	+z panel	13	Battery
7	Battery box		

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2.3 Structural Analysis

Withstanding launch and orbital environment

- **Thermal analysis**
  - The following shows the thermal equilibrium when the satellite is approximated as a single object.

$$mc\frac{dT}{dt} = Q_t - \varepsilon\sigma A F_S T^4$$

m : satellite mass

c : average specific heat of satellite materials as a whole

T : satellite temperature

t : time

ε : solar panel average emissivity

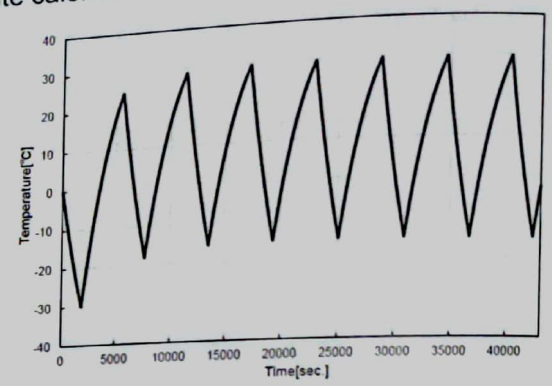
σ : Stefan-Boltzmann constant (5.669×10^{-8} [$W/(m^2\cdot K^4)$])

A : total area of solar panels on all 6 sides

F_S : radiation configuration factor between satellite and deep space: 0.8

Q_t : sum total of external thermal input and satellite calorific value

- Solving this equation gives us the result shown in the figure on the right. The serrated pattern is characteristic because the satellite is repeatedly exposed to shadows and sunlight.
- More detailed results can be obtained by increasing the number of nodes as required.



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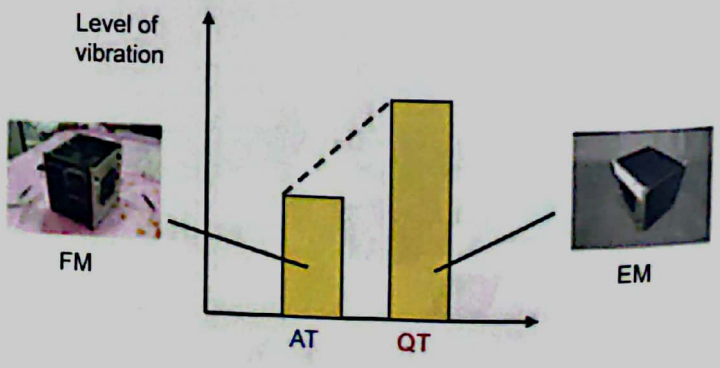
2.4 Environmental Test

Withstanding launch and orbital environment

- **Vibration test and impact test**
  - The purpose of the test is to confirm that the satellite will not be destroyed by vibrations or shocks generated during rocket launch.
  - There are 2 tests known as QT (Qualification Test) and AT (Acceptance Test) that are performed depending on the level of vibration/shock applied.
  - QT is a test performed under more stringent conditions than expected at launch using engineering models (EM). This is performed to ensure that the design margin is adequate.
  - AT is a test performed using a flight model (FM) under the same conditions as expected at launch. There is no manufacturing error in FM. It is performed to ensure that conditions are acceptable.



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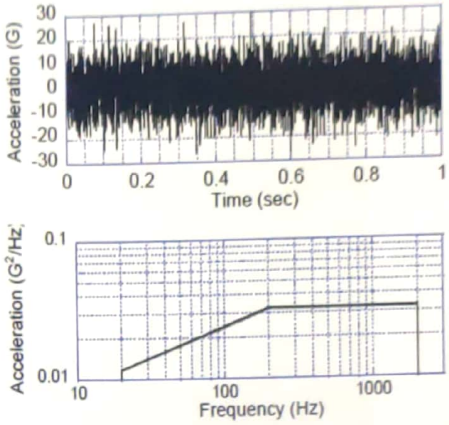
2.4 Environmental Test — Withstanding launch and orbital environment

- **Vibration test: random vibration test**
  - In this test, the base vibrates at different vibration frequencies. Typically, the PSD (Power Spectral Density) spectrum is estimated based on the launch vehicle, and the satellite is tested accordingly.
  - ** ~ **** [Hz]: ○ [G^2/Hz] means that PSD increases between ** and **** [Hz], realizing an oscillating frequency of ○ [G^2/Hz]. * ~ ** [Hz]: + *** dB/oct means that in the * to ** [Hz] range in which the oscillating frequency increases, PSD increases by *** dB for every 1 increase in octave.

Test Type	Test Conditions
Random	* ~ ** [Hz]: + *** dB/oct, ** ~ **** [Hz]: ○ [G^2/Hz], □ [min]



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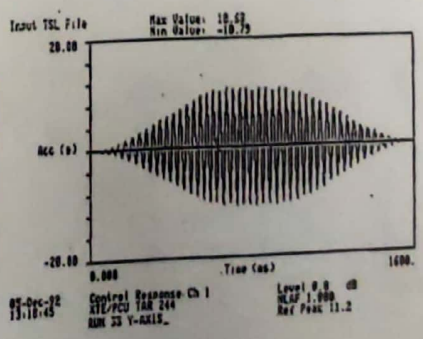
2.4 Environmental Test — Withstanding launch and orbital environment

- **Vibration test: sine burst test**
  - In addition to vibration, it is generally necessary to ensure that the satellite is not destroyed under static acceleration loads.
  - However, due to the large size of the equipment, it is difficult to create a static acceleration load.
  - The sine burst test therefore uses a shaker to simulate a static acceleration load.
  - The sine burst test sequence is as follows: Amplitude is gradually increased at low frequency. It is then corrected so that the acceleration amplitude exceeds the required value of static acceleration load value, and finally, the amplitude is decreased after multiplying the vibration by approximately 10.

Type of test	Test conditions
Sine burst	**Rocket axis direction** * ~ ** [G]
	Rocket axis orthogonal direction *** ~ **** [G]



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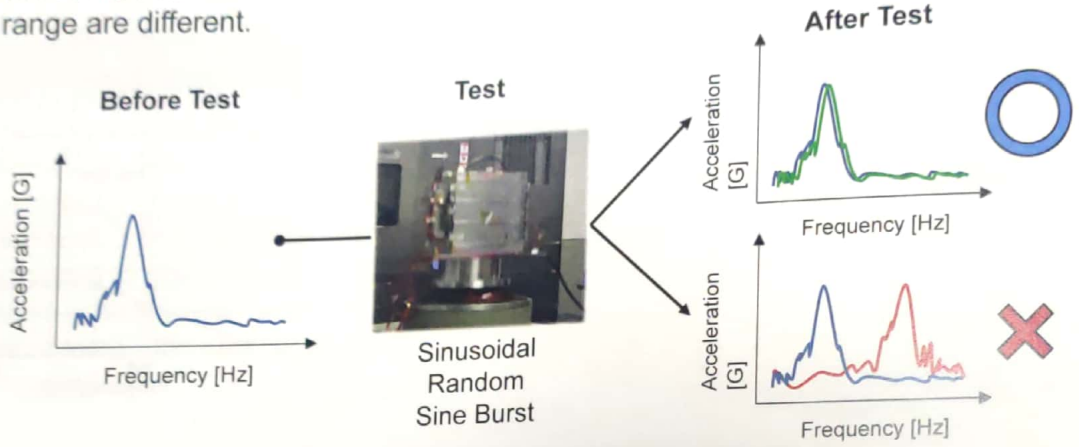
2.4 Environmental Test — Withstanding launch and orbital environment

- **Vibration test: modal survey**
  - The purpose of the vibration test is to check whether the satellite will be damaged, or if any defects will occur when vibration is applied.
  - In many cases, resonance frequencies are measured and compared before and after the vibration test. The resonance frequency will be changed if something happens during the test, and so it is necessary to compare the frequencies to make sure that there is no change.
  - In modal investigations, the required sinusoidal vibrations are usually applied at relatively low acceleration levels. In other words, the method is the same as that for the sinusoidal vibration test, but the acceleration amplitude and vibration frequency range are different.



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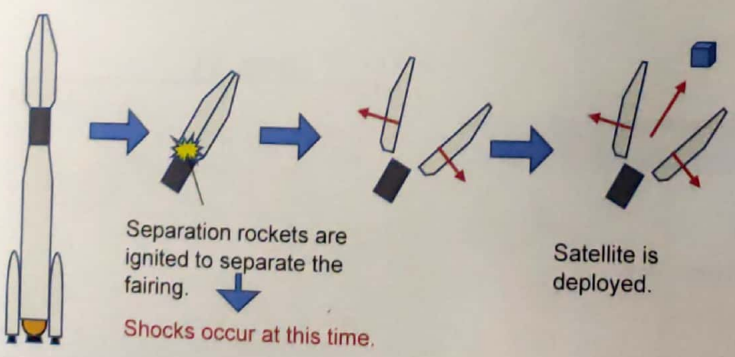
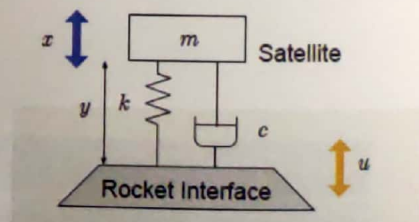
2.4 Environmental Test — Withstanding launch and orbital environment

- **Impact test**
  - The purpose of the impact test is to ensure that the satellite can withstand the impact of the rocket fairing separation.
  - Impact conditions are typically specified using SRS (Shock Response Spectrum).
  - SRS (Shock Response Spectrum) is the accelerometer's maximum absolute value at the time of the specimen's acceleration response in a single degree-of-freedom system.
  - If the test value is higher than the required SRS curve, we can say that we have passed the impact test.





$x = y + u$

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

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

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

ζ : given by rocket provider

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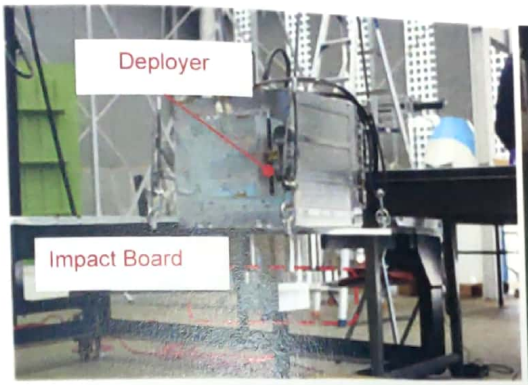
2.4 Environmental Test

Withstanding launch and orbital environment

- **Impact test**
  - The impact test differs slightly from the vibration test in that EM and FM have the same level of influence. With EM, impact resistance is evaluated by applying twice as much impact as would be expected during launch.
  - The test equipment employs a simple device such as a gas gun or spring to fire a projectile at a sample.
  - Since the impact is transmitted from the joint with the rocket at the time of the actual launch, the impact is transmitted to the satellite via an impact board in order to simulate this.



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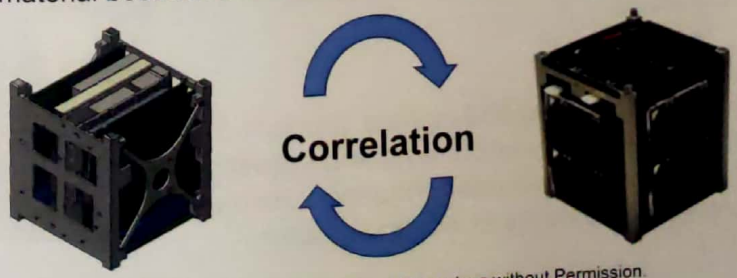
2.4 Environmental Test

Withstanding launch and orbital environment

- **Correlation**
  - The natural frequencies obtained from the tests should be compared with those obtained from the analysis, and the mathematical model should be adjusted to account for the differences.
  - It is extremely difficult to determine the cause of the difference between the mathematical model and actual unit. The amount of required to track errors depends on the purpose and situation.
  - The following errors tend to occur:
  - **Material constant differences:** Difference in Young's modulus between mathematical model and actual unit, etc.
  - **Modeling error:** Degree of detail that must be used when modeling the actual unit.
  - **Securing method differences:** Since the actual unit is secured with screws, stress is applied by the extent that the screws are tightened, unlike "securing" or "simple support" in the field of material mechanics.
  - **Effect of attenuation:** Attenuation is as simple as the resonance frequency being changed by adhesive material because the resonance frequency can be distributed.



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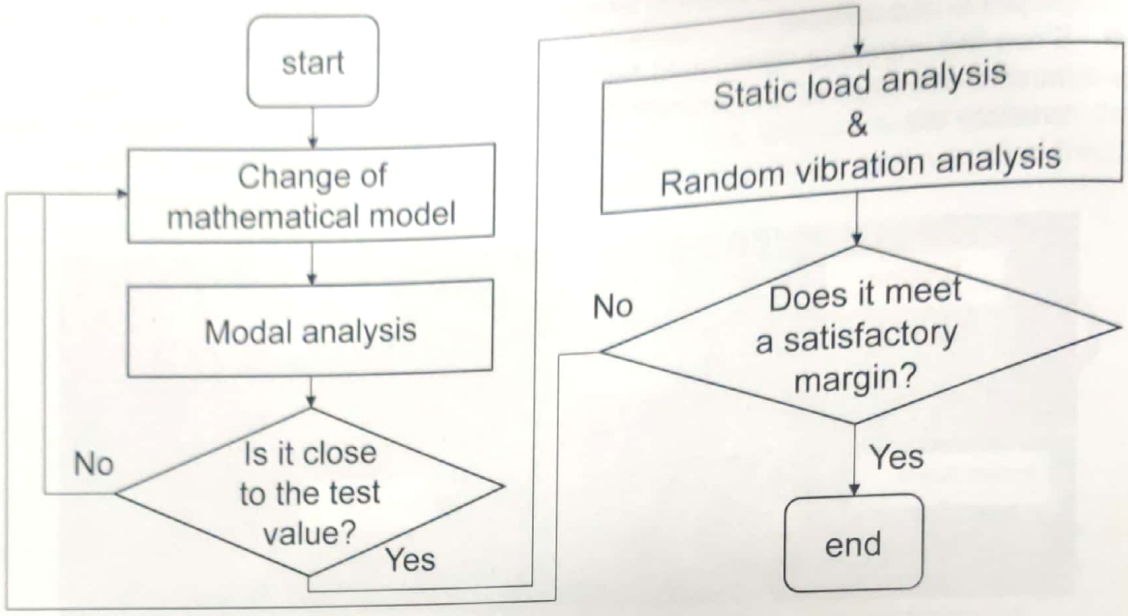
2.4 Environmental Test Withstanding launch and orbital environment

- **Correlation**
  - The following is an overview of the correlation process:
  - Stress analysis is complete when the prescribed margin of safety is achieved.



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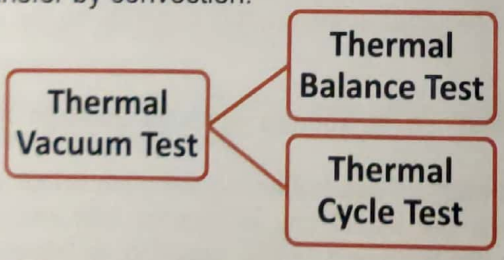
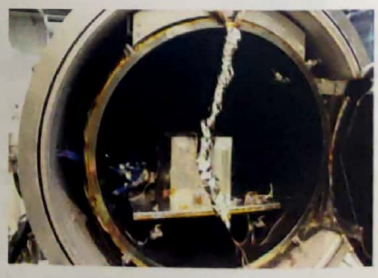
2.4 Environmental Test Withstanding launch and orbital environment

- **Thermal test: thermal vacuum test**
  - This test is performed to evaluate the suitability of the thermal control design, and to ensure that the satellite functions properly in a thermal environment/vacuum in orbit.
  - In a vacuum, the temperature distribution is not uniform because there is no heat transfer by convection.





- **Purpose of test**

  (1) Thermal balance test
  - Verify the suitability of the satellite's thermal control design.

  (2) Thermal cycle test
  - Verify that the satellite functions properly in an orbital thermal environment, and satisfies the required function/performance criteria. Verify that the satellite is working properly.

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2.4 Environmental Test

Withstanding launch and orbital environment

- **Thermal test: thermal vacuum test**

(1) Thermal balance test

- This is used to evaluate the suitability of the thermal control design by exposing the satellite to a thermal vacuum environment that simulates the environment in which the satellite would be exposed to in orbit.

- For example, testing is conducted under the following conditions.
  - Low temperature = minimum heat input in orbit + minimum heat from internal equipment
  - High temperature = maximum heat input in orbit + maximum heat from internal equipment

- By examining the thermal balance, we can determine the maximum and minimum temperatures for each piece of equipment.
  - Verify that the temperature of each piece of equipment is within the operating temperature range.
    → Verify the suitability of the thermal control design.
  - Comparison of estimated temperatures obtained using thermal mathematical models and test measurement results.
    → Verify the suitability of the thermal mathematical models.
  - Heat input is included as a test condition, but in principle, the temperature is not set so that the temperature response of each piece of equipment can be evaluated.

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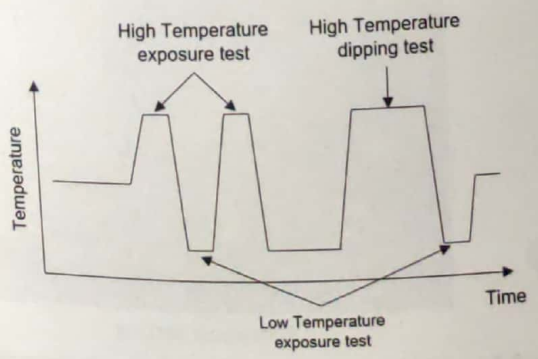
2.4 Environmental Test

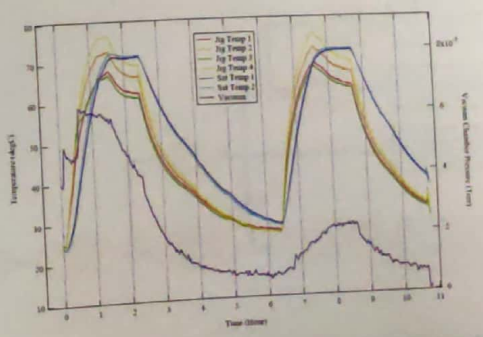
Withstanding launch and orbital environment

- **Thermal test: thermal vacuum test**

(2) Thermal cycle test

- This is used to evaluate the suitability of the thermal control design by exposing the satellite to a thermal vacuum environment that simulates the environment in which the satellite would be exposed to in orbit.
- Configure the heat input to allow a margin for the equipment temperature around the highest and lowest temperatures obtained based on results of the analysis performed using mathematical modeling.
- The following cycle tests demonstrate that satellites can withstand the temperature fluctuations of sunlight and shadows in orbit by ensuring that they function properly.





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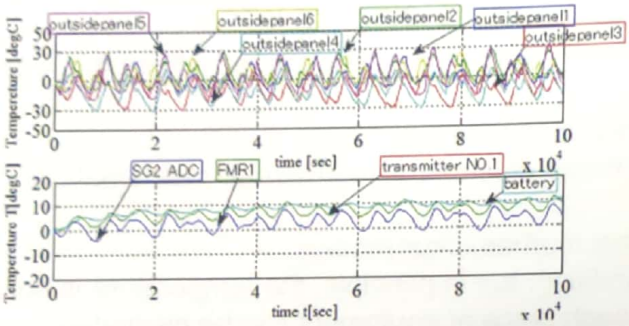
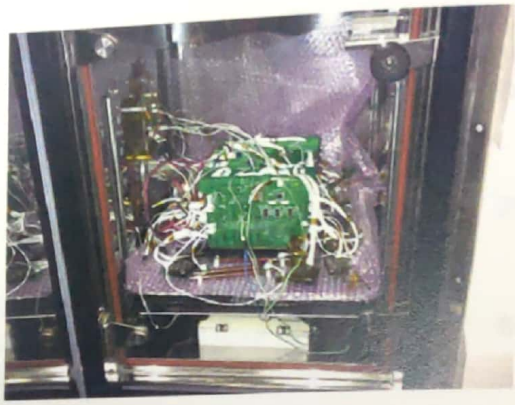
2.4 Environmental Test Withstanding launch and orbital environment

- **Thermal test: thermostatic chamber test**

(2) Thermal cycle test

- This test is used to ensure that the satellite functions properly in a thermal environment in orbit.
- The difference from the vacuum test is that the temperature in the chamber becomes uniform due to convection.
- Cycle tests can demonstrate that satellites are able to withstand the temperature fluctuations of sunlight and shadows in orbit by ensuring that they function properly.
- The temperature sensor mounted on the satellite is calibrated.





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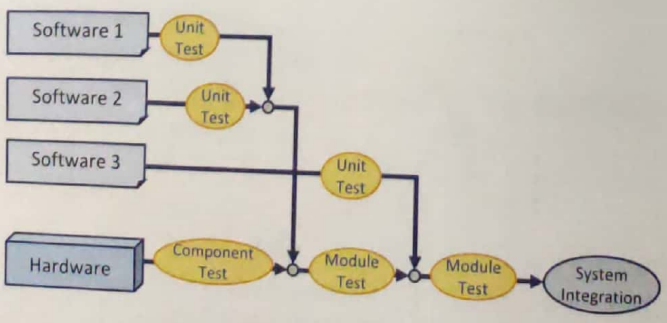
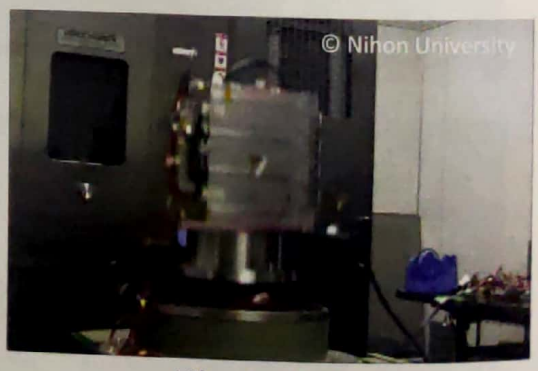
2.4 Environmental Test Withstanding launch and orbital environment

- **"Test like you fly"**
  - Test as many expected functions as possible before interfacing it with other systems.
  - Environmental testing includes vibration testing, thermal vacuum testing, shock testing, EMI/EMC testing, and anything else required by the launch vehicle provider.
  - Keep the scope small with testing and add components systematically, testing them along the way.
  - It is also useful to test individual subsystems before integrating all components. This allows for early detection of design problems and reduces excessive testing of the entire system.
  - Never assume that a board or subsystem that works well in standalone testing will work well when integrated with other boards or subsystems.





Vibration Testing

Pre- and post-test inspections, measurements, and functional demonstrations are important.

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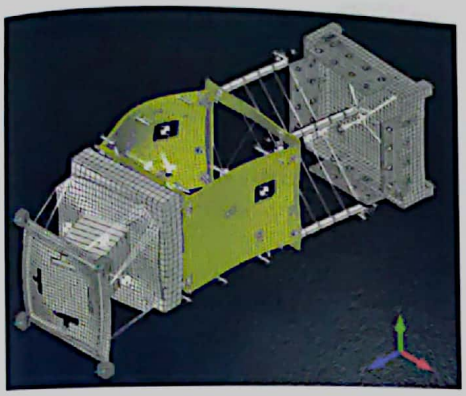
2.4 Environmental Test

Withstanding launch and orbital environment

- **"Test like you fly"**
  - Tests and simulations ensure that everything works properly before putting it into orbit.
  - Structural analysis, Attitude and Orbit analysis, Thermal analysis, Electricity analysis, etc.

Structural Analysis

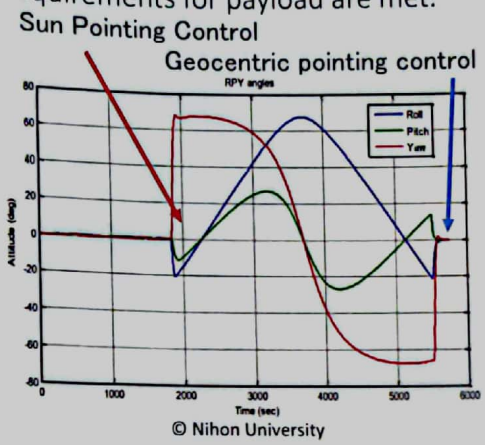
Check whether the structural requirements for payloads are met.



3U CubeSat Origami-Sat © Tokyo Institute of Technology

Attitude and Orbit Analysis

Check whether the attitude and orbit requirements for payload are met.



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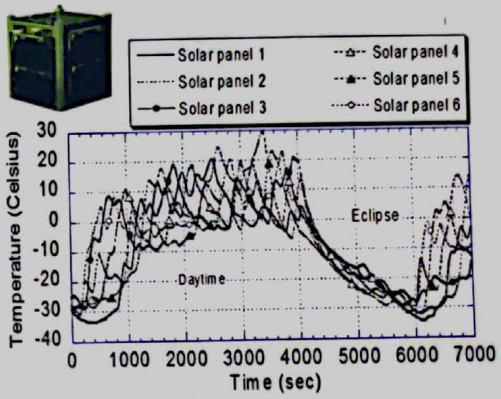
Thermal Analysis

Check whether the thermal requirements for payload are met.



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Is the design fully capable of meeting all the requirements and constraints?

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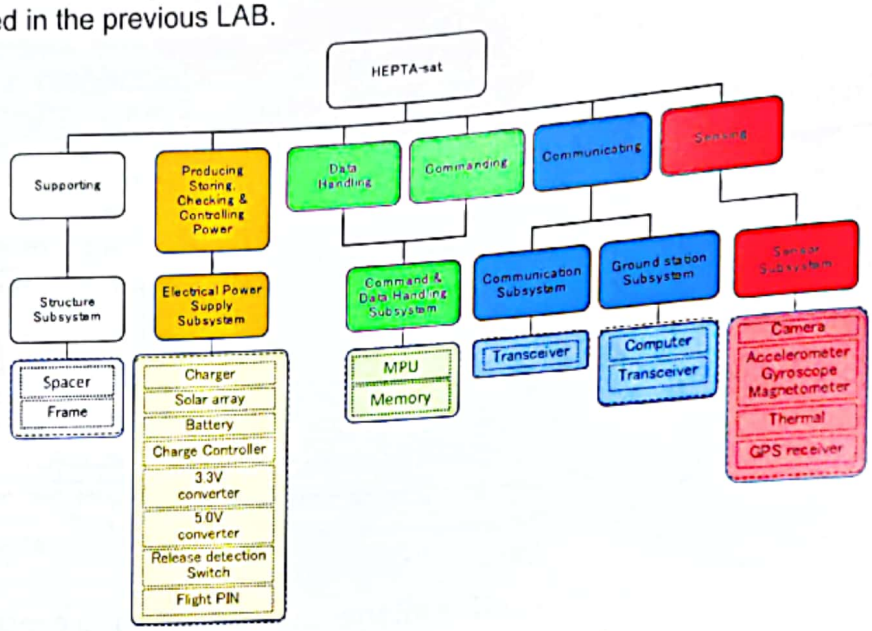
1. What is Structure Subsystem?
   a. Understand roles and functions
   b. Understand the physical structure (system diagram)
2. How to design Structure Subsystem
   c. Understand design of Structure subsystem
3. **Assembly, Integration and Test**
   d. **Understand how components are integrated and tested**
   e. **Experience assembly, integration, and test (AI&T)**
4. **Appendix**

3.0 Overview of assembly, integration and test of HEPTA-Sat kit

- From this point, let's try and gain an understanding of the sensor subsystem by experiencing the system integration process of HEPTA-Sat kit assembly, integration, and testing. We will integrate the elements of the structure subsystem into the subsystems integrated in the previous LAB.



Functional and Physical relation diagram

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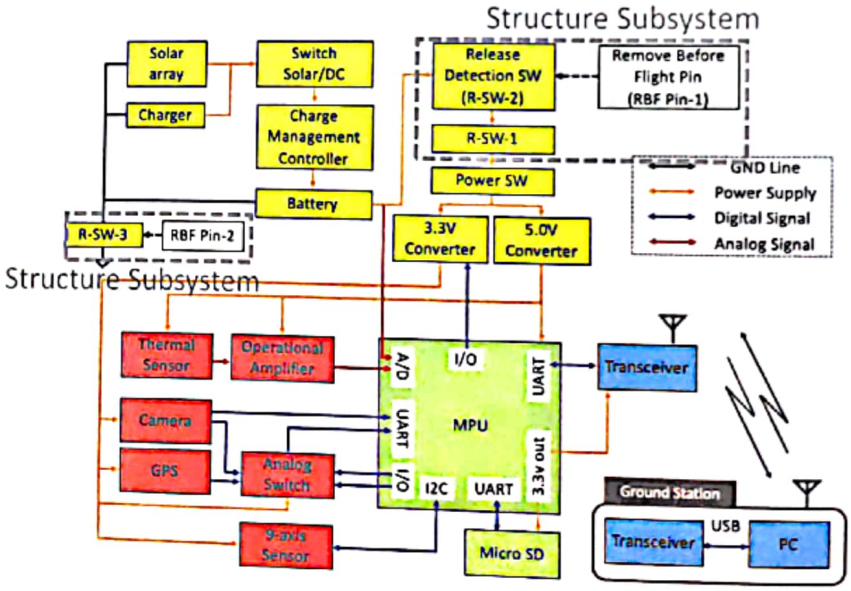
3.0 Overview of assembly, integration and test of HEPTA-Sat kit

- The following is a system diagram of the HEPTA-Sat kit.
- The structure subsystem is equipped with a triple redundancy release detection function using three release switches, two flight pins, and a function used to mount and secure three boards, a solar cell, a camera, and a GPS to the housing.



HEPTA-Sat System diagram

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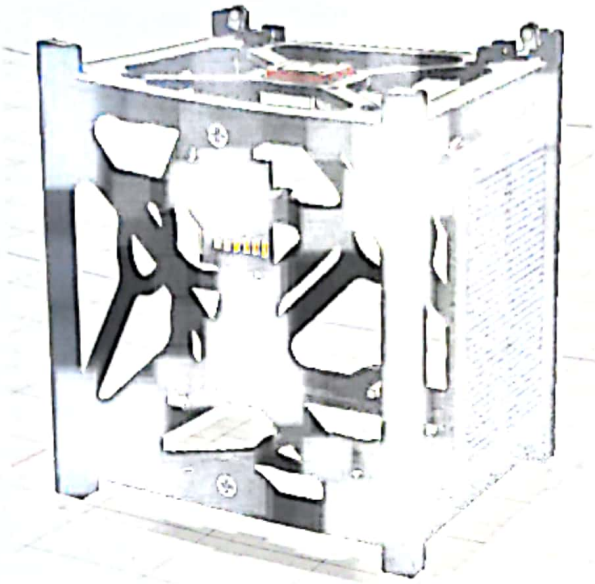
3.0 Overview of assembly, integration and test of HEPTA-Sat kit

Design of HEPTA-Sat Structure

- Let's take a closer look at the structural design of HEPTA-Sat.
- **Each shape, such as holes or protrusions, is intended. Let's read and find out the intention of the design.**



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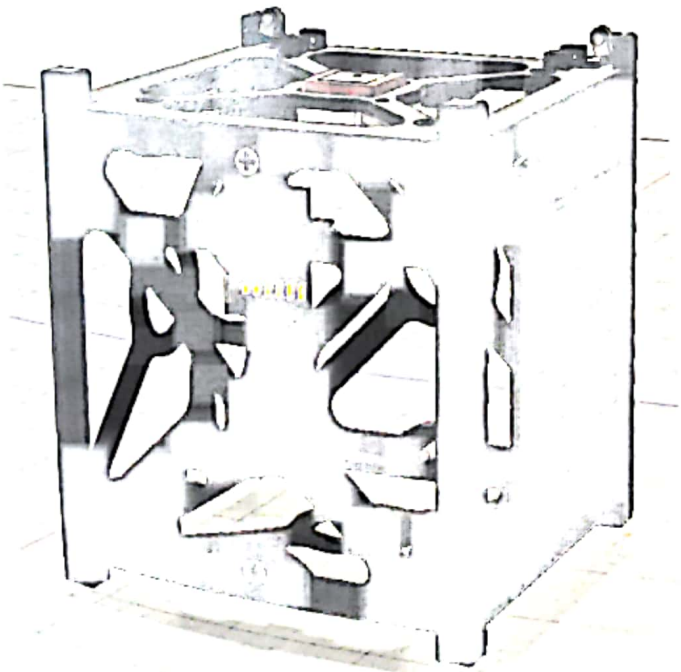
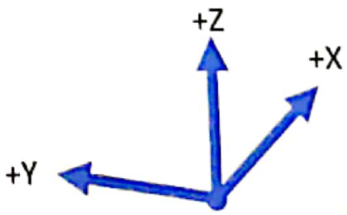
3.0 Overview of assembly, integration and test of HEPTA-Sat kit

Design of HEPTA-Sat Structure

- HEPTA-Sat consists of 3 boards housed in a structure made of Onebody Side Panel (4 side panel) and a top and bottom panel.





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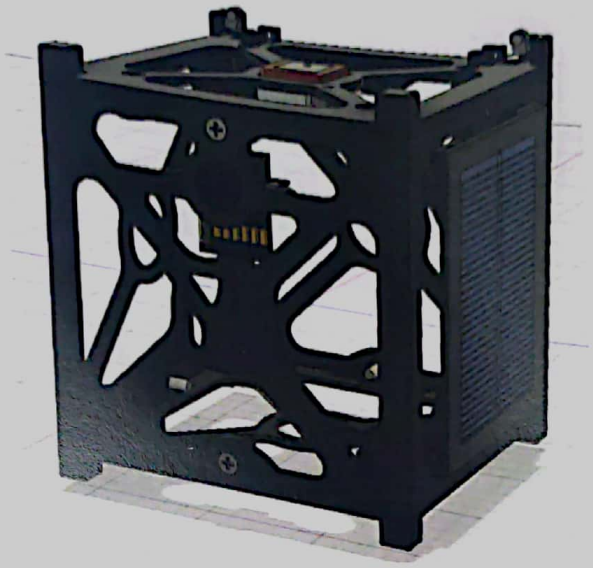

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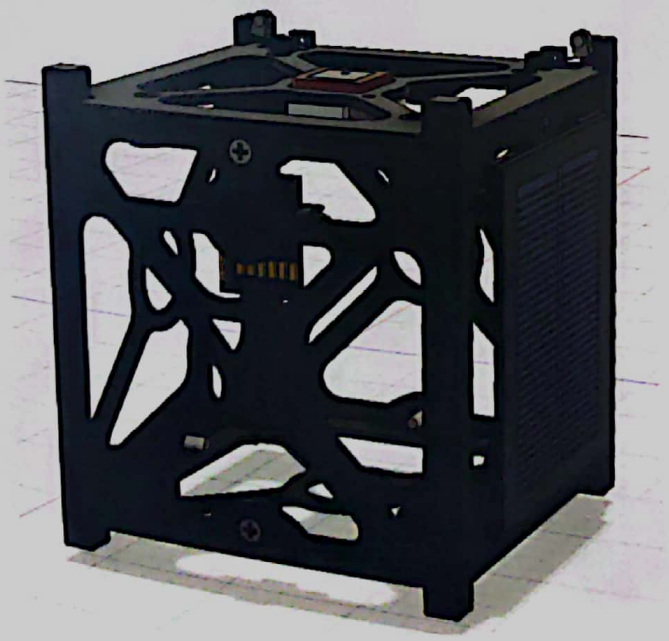

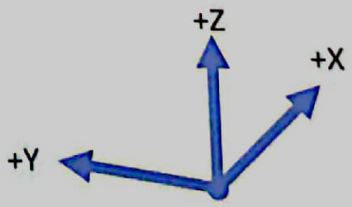

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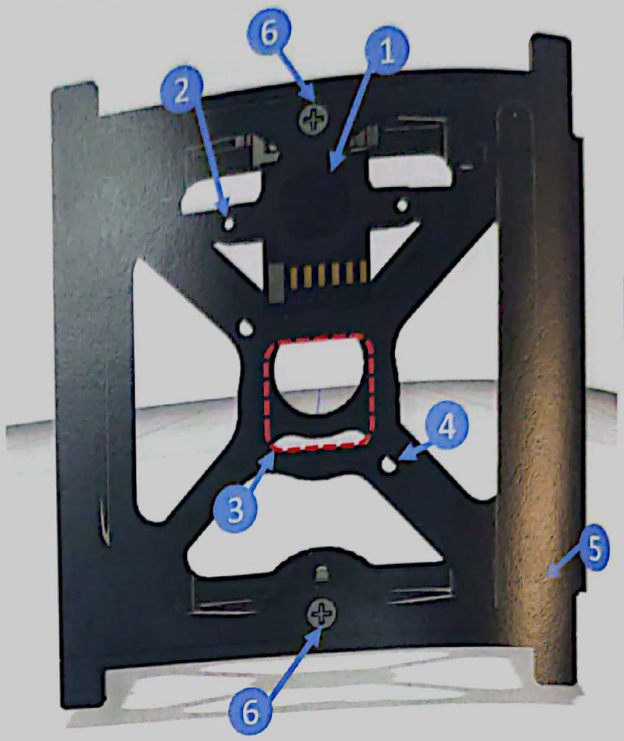
3.0 Overview of assembly, integration and test of HEPTA-Sat kit

Design of HEPTA-Sat Structure

- **−X Panel Design**
  1. Structure for mounting the camera.
  2. Holes for screws to mount the camera.
  3. When using the user board, the GPS unit cannot be attached to the +Y panel, so a GPS unit can be attached here as a spare.
  4. Hole for screws to mount the GPS unit.
  5. Structure for mounting antenna.
  6. Hole for screws to secure the 4 sides to the +Z and −Z panels.



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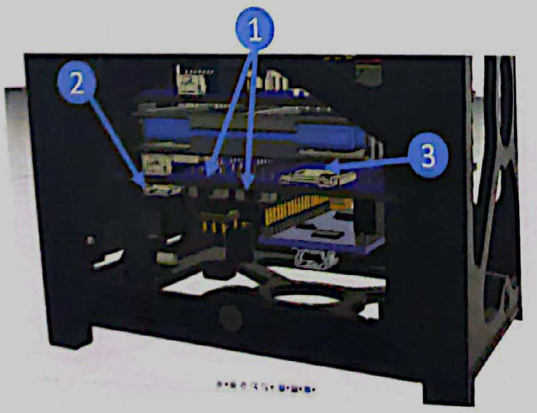
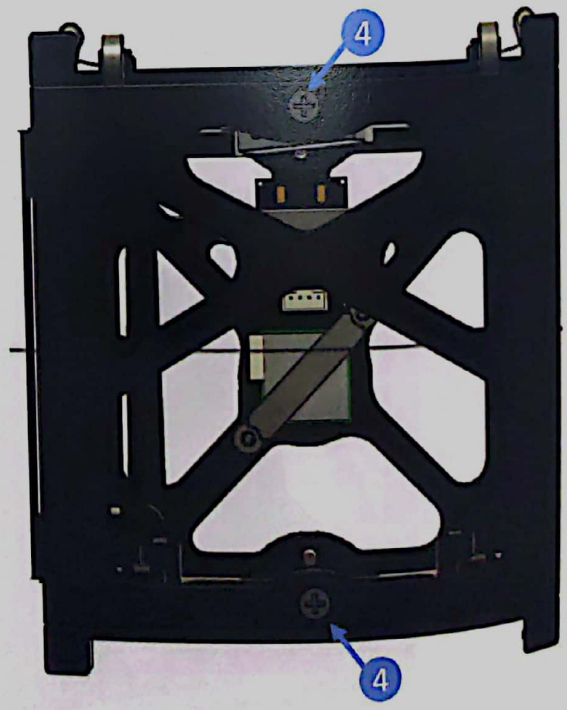
3.0 Overview of assembly, integration and test of HEPTA-Sat kit

Design of HEPTA-Sat Structure

- **+X Panel Design**
  1. Access to ON/OFF switch.
  2. Access to charging port.
  3. Access to micro SD card slot.
  4. Holes for screws to secure the +Z and −Z panels and all 4 sides.





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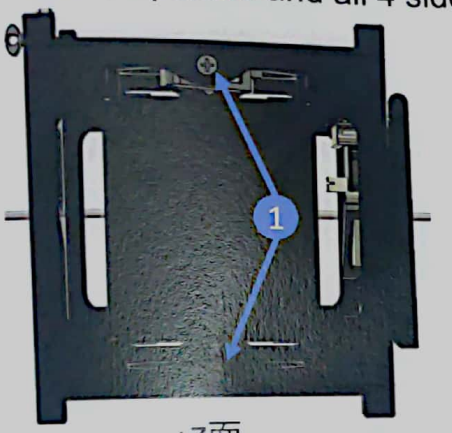
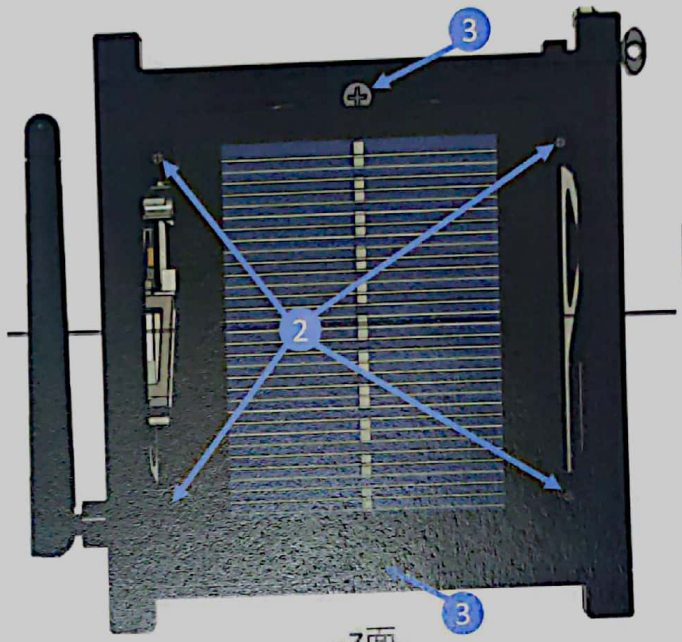
3.0 Overview of assembly, integration and test of HEPTA-Sat kit

Design of HEPTA-Sat Structure

- **+Y Panel Design**
  - ① Holes for screws to secure the +Z and −Z panels and all 4 sides.
- **−Y Panel Design**
  - ② Holes for screws to secure the solar panel.
  - ③ Holes for screws to secure the +Z and −Z panels and all 4 sides.



+Z面



-Z面

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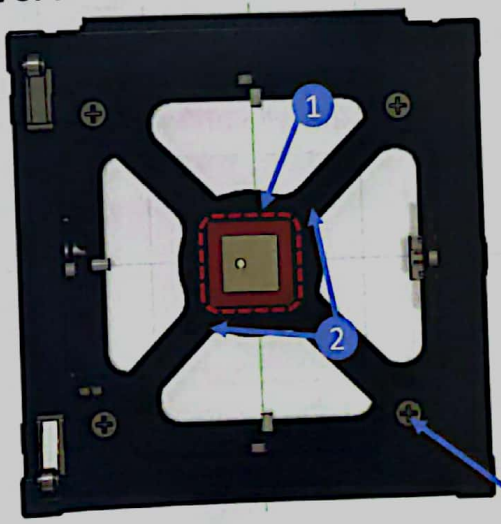
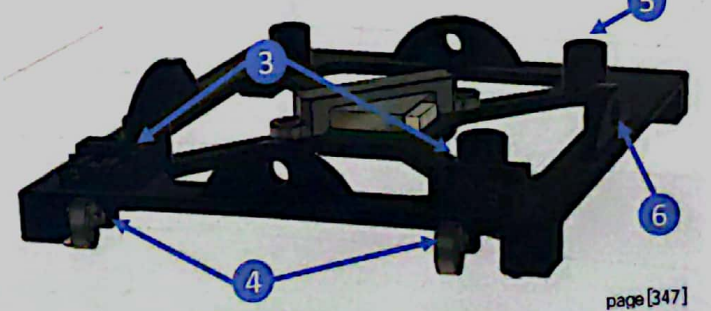
3.0 Overview of assembly, integration and test of HEPTA-Sat kit

Design of HEPTA-Sat Structure

- **+Z Panel Design**
  - ① Structure for mounting the GPS unit.
  - ② Holes for screws to mount the GPS unit.
  - ③ Structure to mount the Release Detection Switches (2).
  - ④ Holes for the Remove Before Flight pins.
  - ⑤ Structure for mounting the circuit boards inside.
  - ⑥ Holes for screws to secure all 4 sides (+X, −X, +Y, −Y) to the +Z panel





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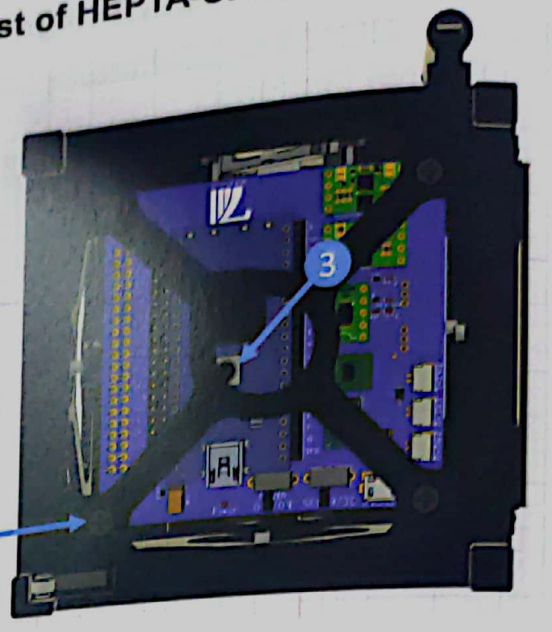
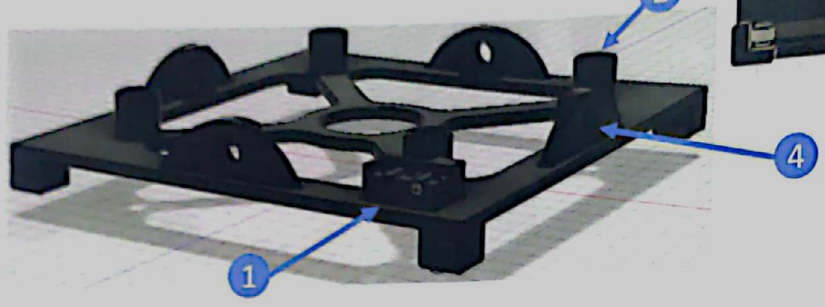
3.0 Overview of assembly, integration and test of HEPTA-Sat kit

Design of HEPTA-Sat Structure

- **−Z Panel Design**
  - ① Structure for mounting the Release Detection Switch (1).
  - ② Structure for mounting the circuit boards inside.
  - ③ Access to the mbed button.
  - ④ Holes for screws to secure all 4 sides (+X, −X, +Y, −Y) to the −Z panel.





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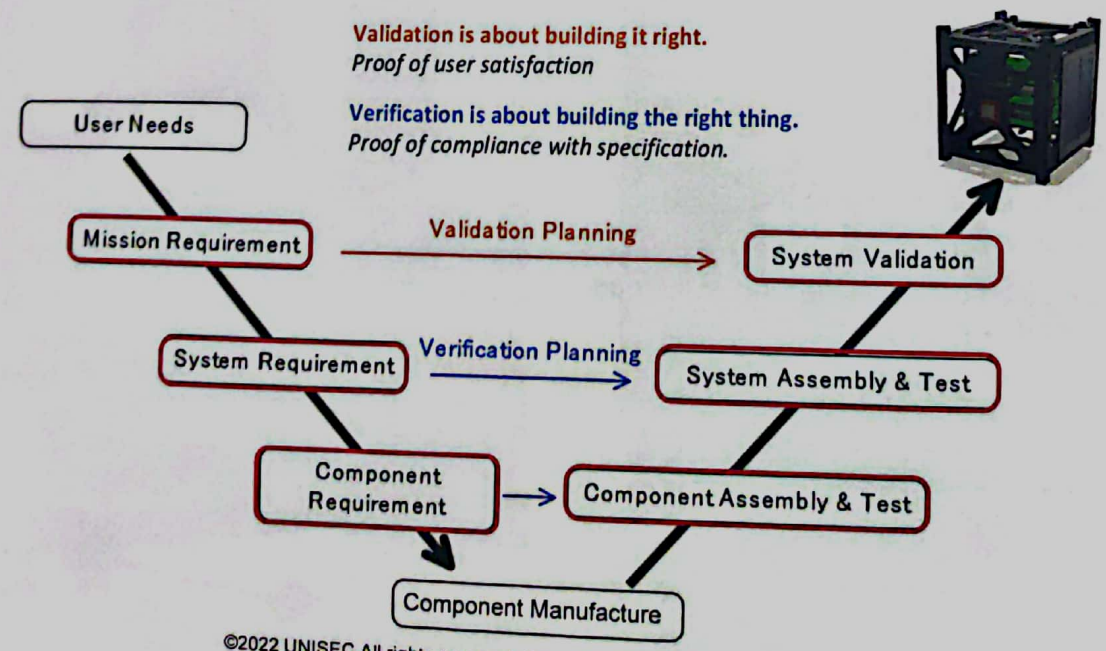
3.0 Overview of assembly, integration and test of HEPTA-Sat kit

- The assembly, integration, and testing of CubeSat is a phase in which the requirements for each element, each subsystem, and each system from the mission are all verified to be met.
- In this section, we will assemble, integrate and test HEPTA-Sat, starting with "each component element" in turn.



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3.0 Overview of assembly, integration and test of HEPTA-Sat kit

- You may want to prepare a Verification Matrix that summarizes information such as what is to be verified, and how it is to be verified as follows.

No	Function requirement	Verification item example	Verification method example
1	Follow Constrains of Launcher	• Mounting satellite on rocket and ensuring that combined weight is within max. permissible weight. • Maintaining assembly accuracy after fitting into the POD.	• Ensure that the structure is securely fastened during assembly. • Perform a fit check to ensure that the satellite fits into the POD. • Perform measurement, ensuring that the dimensional error is within ± 0.5 mm, to check the size. • Measure the weight to check.
2	Release Detection	• Power does not turn ON while in POD.	• Perform a fit check to ensure that the power is OFF. • Ensure that the power is OFF during the vibration test.
3	Hold Component	• Mounted equipment should be secured.	• Perform a vibration test to confirm that the equipment is properly secured.
4	Access System from outside of POD	• It should be possible to access the system even after insertion into the POD.	• Ensure that the access port is operational with a fit check.
5	Switch Power / Charging	• Neither charging nor power supply should occur unexpectedly.	• Ensure that the power does not turn ON while the flight pin is inserted.

• In the example above, the functions and verification items are represented as a large group for simplicity. In practice, the functions and verification items will be more detailed so that there are no omissions in the verification method.
• It may be better to specify (to ensure traceability) where each request to the subsystem comes from across the satellite system.

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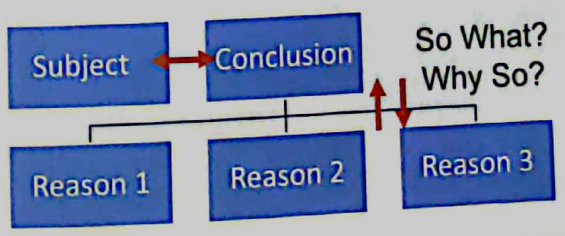
3.0 Overview of assembly, integration and test of HEPTA-Sat kit

- Debug is a process of discovering a problem, isolating it and rectifying it, or displacing it and evaluating it by tests. The following is a debug example about defective SD card:
- Come up with potential causes and devise a response plan
  - Cause (1): Power is not on properly
  - Cause (2): SD failed
  - Cause (3): SD card is inserted the wrong way
  - Cause (4): SD card needs to be formatted

- ☐ So What?: **Try drawing a conclusion** from the available information.
- ☐ Why So?: So What? **Check** to see if the conclusion and reasons make sense.



- At each level, the message is a summary of downstream groups, and the conclusion is at the top. One group shares the same message, and the selection of horizontal elements should follow the MECE principle.

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3.1 Check parts and components

- First, **let's check** the parts to be assembled.

No.	Subsystem	Part Name	Quantity
3	User	User Board	1
7	EPS	Solar cell with Jig	1
21	Sensor & Comm.	Antenna for HEPTA-Sat	1
26	Structure	Spacer 5.5×25 Female-Female	4
27	Structure	Flight Pin	2
28	Structure	GPS Jig	1
29	Structure	Camera Jig	1
31	Structure	Screw M3	16
32	Structure	Screw M1.6	11
34	Structure	Upper Panel	1
35	Structure	Onebody Side Panel	1
36	Structure	Bottom Panel	1

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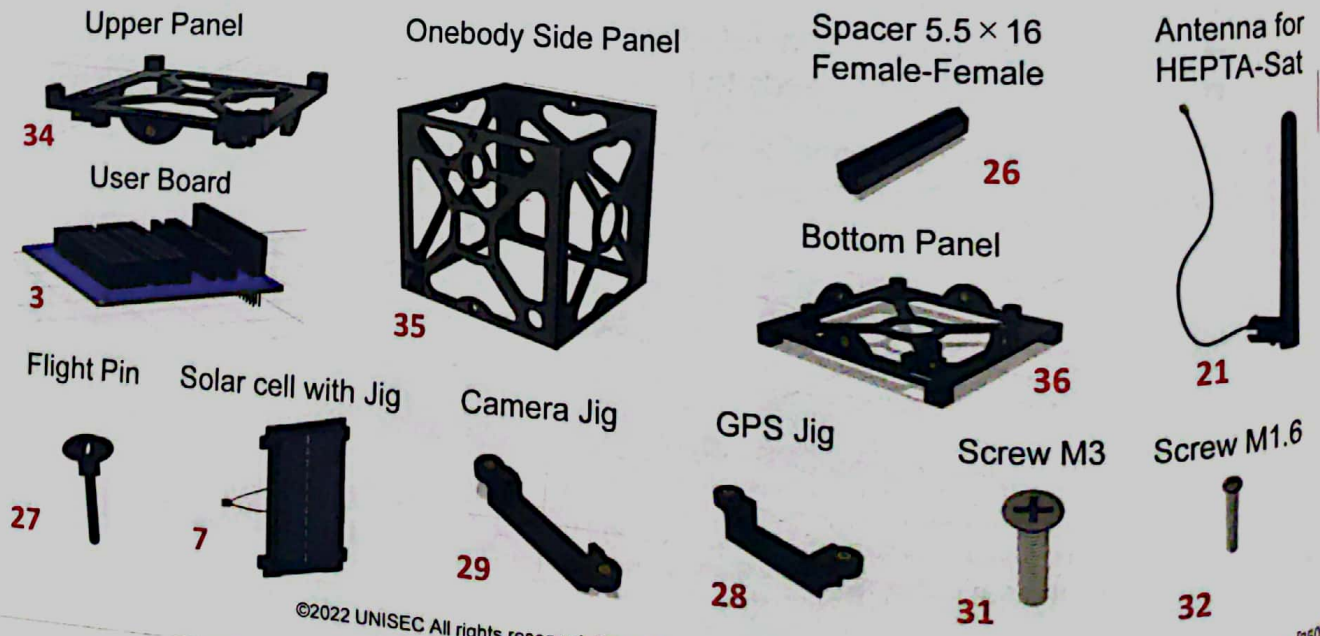
3.1 Check parts and components

- Prepare the components required for AI&T (Assembly, Integration and Test) of the Sensor subsystem.
- It is important to **"install and check one component by one"** in order to understand the behavior and cause of problem. When installing a component, turn off Power switch. Assembly and integration begins on the next page. ※Before assemble Structure, remove Solar Cell with Jig and Antenna from HEPTA-Sat main unit.



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