KiboCUBE Academy

Lecture 15

Introduction to Satellite Testing

Kyushu Institute of Technology

Laboratory of Lean Satellite Enterprises and In-Orbit Experiment

Director, Professor Mengu Cho, Ph.D.

This lecture is NOT specifically about KiboCUBE and covers GENERAL engineering topics of space development and utilization for CubeSats.
The specific information and requirements for applying to KiboCUBE can be found at:
https://www.unoosa.org/oosa/en/ourwork/psa/hsti/kibocube.html

Contents

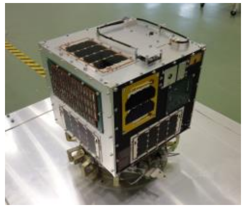
1. Lecturer introduction
2. Chapter 2 Verification
3. Chapter 3 Testing
4. Chapter 4 What tests do we have to do?
5. Chapter 5 Conclusion

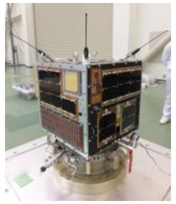
References

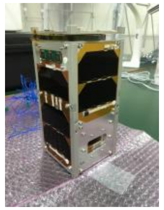
- ISO-19683, “Space Systems – Design qualification and acceptance tests of small spacecraft and units”
- CubeSat assembly, integration, testing and verification, Part.4 in CUBESAT HANDBOOK, edited by Chantal Cappelletti et al., 2020, Elsevier and Academic Press

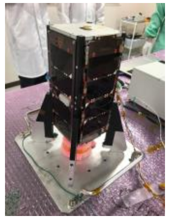
1. Lecturer introduction

1. Lecturer introduction









Mengu Cho, Ph.D.

(*since 2018)
(**since 2020)

Position:

2004 - Professor, Department of Space Systems Engineering*
Director, Laboratory of Lean Satellite Enterprises and In-Orbit Experiments **
Kyushu Institute of Technology, Japan

2021 – Visiting Researcher, Chiba Institute of Technology, Japan

2014 - Visiting Professor, Nanyang Technological University, Singapore

2013 - Coordinator, Nations/Japan Long-term Fellowship Programme, Post-graduate study on Nano-Satellite Technologies (PNST)

Research Topics:

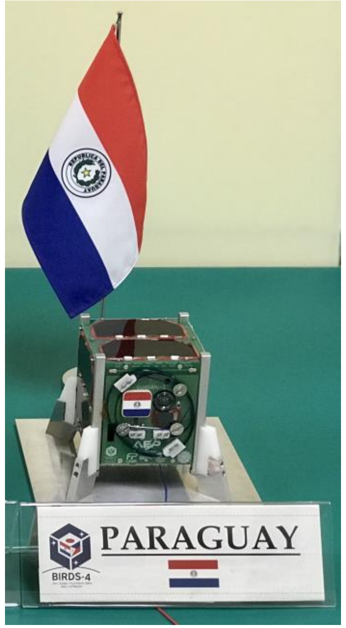
Lean Satellite, Spacecraft Environment Interaction

2. Verification

2. Verification

2.1 What to do when we build a satellite?

- Ask stakeholders/customers/users what needs they have (customer requirement)
  - Think about how the satellite solves the needs (mission requirement)
    - Overall specification of the satellite to meet the mission requirement (system requirement)
      - Specification of each component (component requirement)



Paraguay’s first satellite GUARANISAT-1 will collect data on triatomine bugs

Stakeholder requirement:
Investigate the habitat of insects carrying parasites

Mission requirement:
Collect information of bug-traps in remote villages from space

System requirement:
Receiving information from the field and forward it to the researcher

Component requirement:
Transceiver capable of VHF uplink and UHF downlink

From Wikipedia

2. Verification

2.1 What to do when we build a satellite?

- Ask stakeholders/customers/users what needs they have (customer requirement)
  - Think about how the satellite solves the needs (mission requirement)
    - Overall specification of the satellite to meet the mission requirement (system requirement)
      - Specification of each component (component requirement)
      - Verify components against component requirement
    - Verify system against system requirement
  - Validate system against mission requirements

Verification: Is the system built right?
Validation: Is the right system built?

2. Verification

2.2 Verification Plan

- Right from the start of the project
- Analyze the requirements and identify programmatic and cost drivers
- Plan the verification program
- Verification matrix
  - Requirement to be verified
  - How to verify
    - Test? Inspection? Demonstration? ----
  - When?
    - Development phase? Design phase? Production phase?
  - Where?
    - In-house? Outside?

Logistics issues

2. Verification

2.3 Verification methods

- Test
- Analysis
- Demonstration
  - “Does this antenna deploy properly?”
  - “Let’s deploy it”
- Inspection
  - Actual hardware
- Review of designs
  - Documents

https://www.youtube.com/watch?time_continue=68&v=gNMSq7VbMvE&feature=emb_logo

Watch from 0:55

2. Verification

2.4 Why do we test?

- Testing makes sure everything works accordingly before it gets into the field (space)
- Space system cannot fail because
  - Expensive
  - Important (political, social, military, etc.)
- Space system is different from other systems (aircraft, automobile, electronics, etc.)
  - No chance of maintenance and repair
  - Complex
  - Limited production run
    - Often only one of a kind
  - Long system life cycle
    - Difficult to accumulate personal experience
    - If you have designed 100 satellites, you know what to do

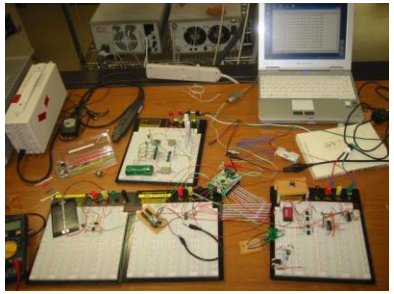
2.5 Test vs Analysis

- Test results are generally more credible than analysis results but some tests are not practical
- While analysis is usually less costly than testing, it is not always the case
- Select based on optimization of the cost and schedule to obtain the best/adequate evidence
- Often, test and analysis are complementary
    - Thermal analysis <-> Thermal tests
    - Structural analysis <-> Mechanical tests

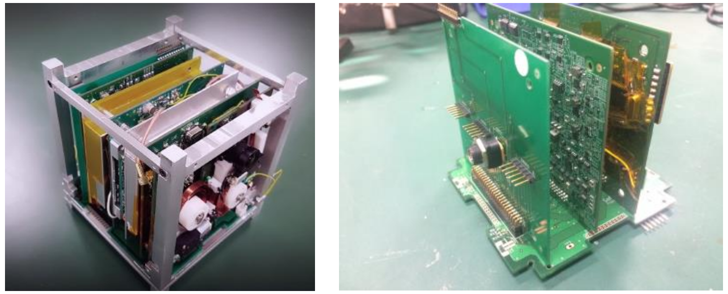
2. Verification

2.6 Satellite development processes

1. Mission definition
2. System configuration design
3. Component/subsystem design
4. Feasibility check using bread-board models (BBM)
5. Making of prototype (engineering model, EM, qualification model (QM))
6. **Verification** of design (**Qualification**)
7. Making of flight model (FM)
8. **Verification** of flight hardware/software (**Acceptance**)



BBM



EM

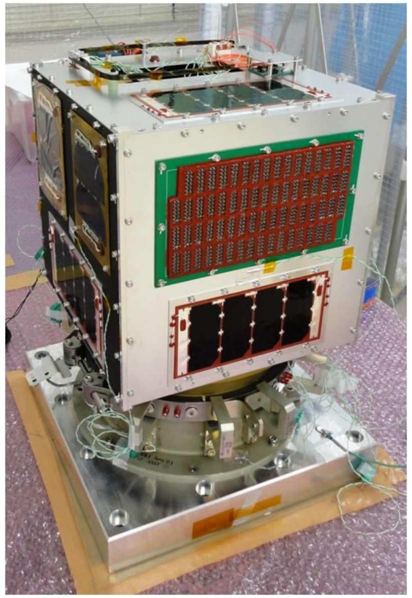
FM

2.7 Verification objectives

- Qualification
  - Is the <u>design</u> fully capable of meeting all the requirements?
  - No need of using flight hardware
  - ‘Over testing’ is acceptable
- Acceptance
  - Is the end product (flight hardware) free from workmanship and material defects?
  - Has flight hardware been built to the <u>qualified design</u>?

2. Verification

2.8 Qualification

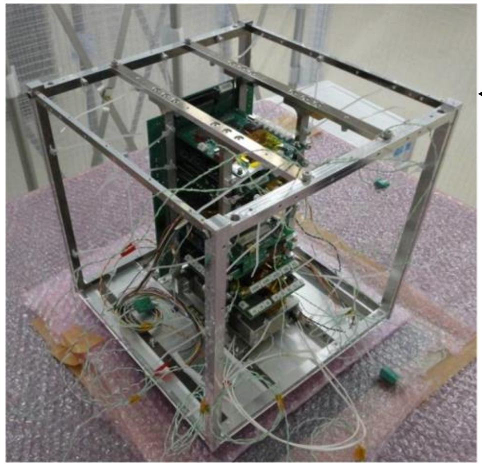


Design requirement for structure (example)

Structure shall have enough strength against mechanical load during the launch phase.

Design adopted

Four main columns inside to withstand the load



Qualification purpose

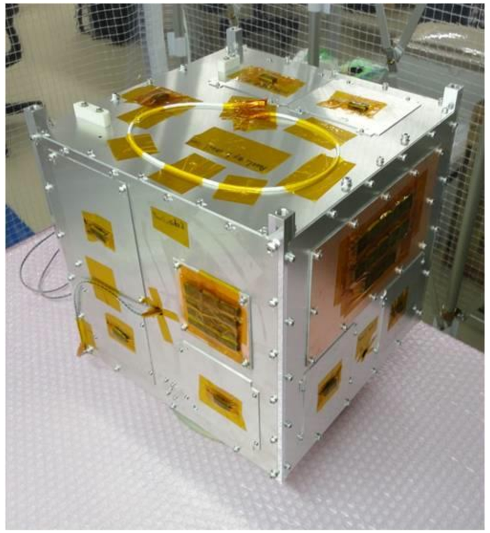
Does this design really withstand the load?

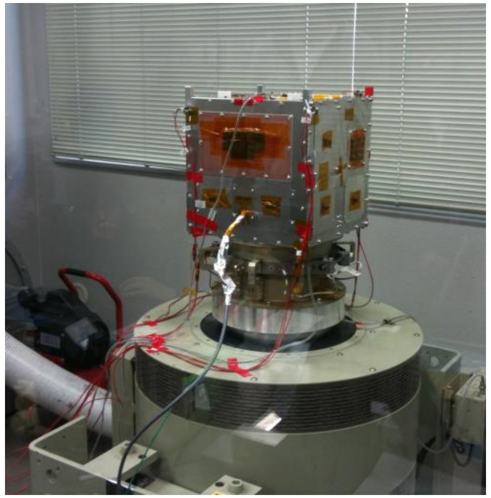
Qualification method

Test & analysis

2. Verification

2.8 Qualification





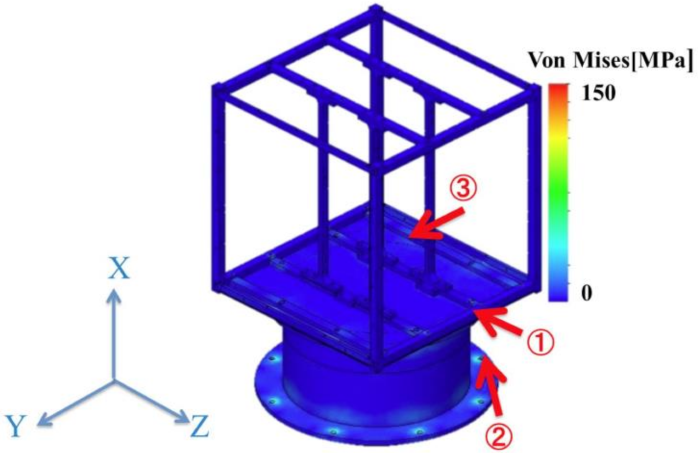
Qualification method

Build a test model and run a test

Apply test load with a margin

1.25x the maximum expected

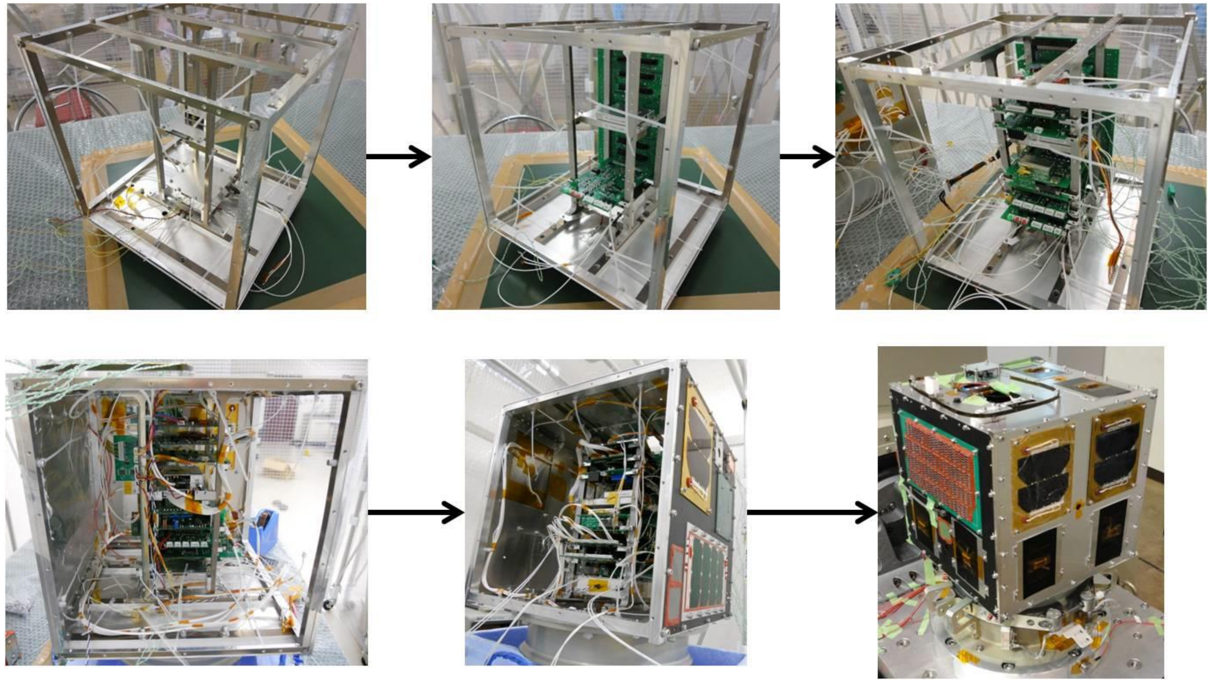
Run analysis



2. Verification

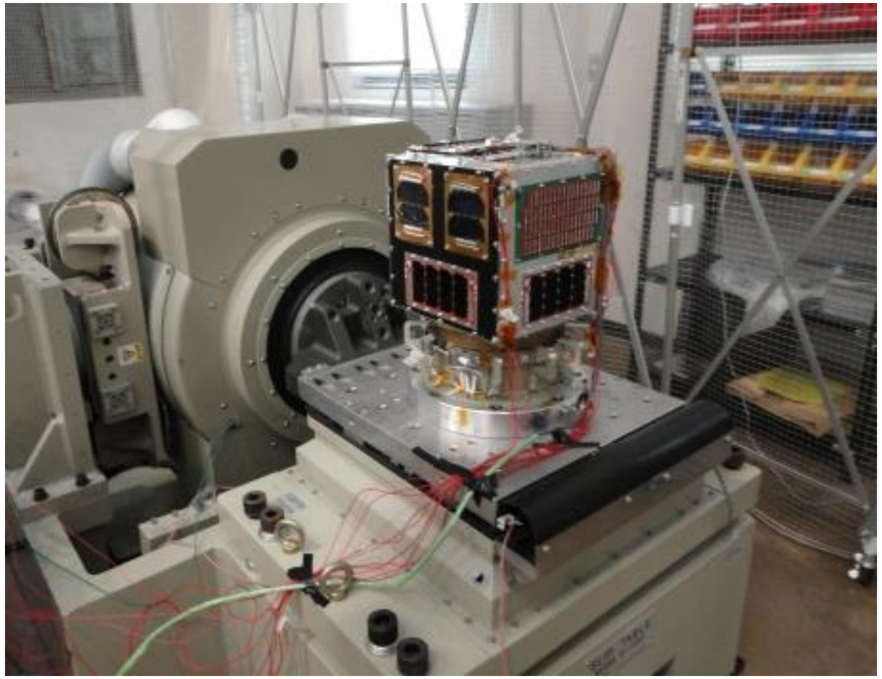
2.9 Acceptance

- Structure design was fixed after qualification
- Flight hardware was built according to the design (drawing)
- Acceptance purpose
  - Did we build the hardware without any error?
- Acceptance method
  - Test



Apply test load

The maximum expected (no margin)



2.10 Margins

NASA-HDBK-7005
March 13, 2001

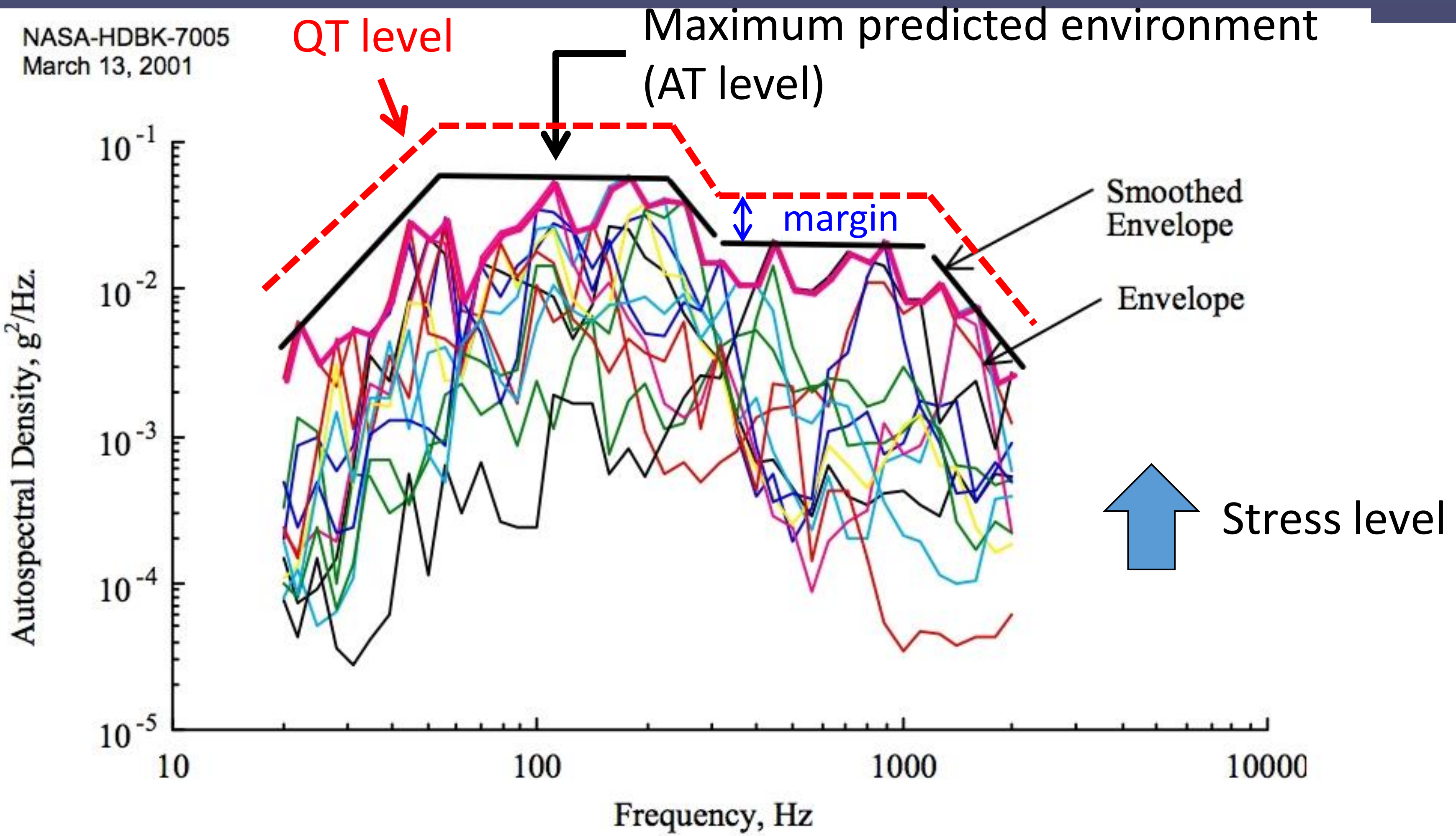
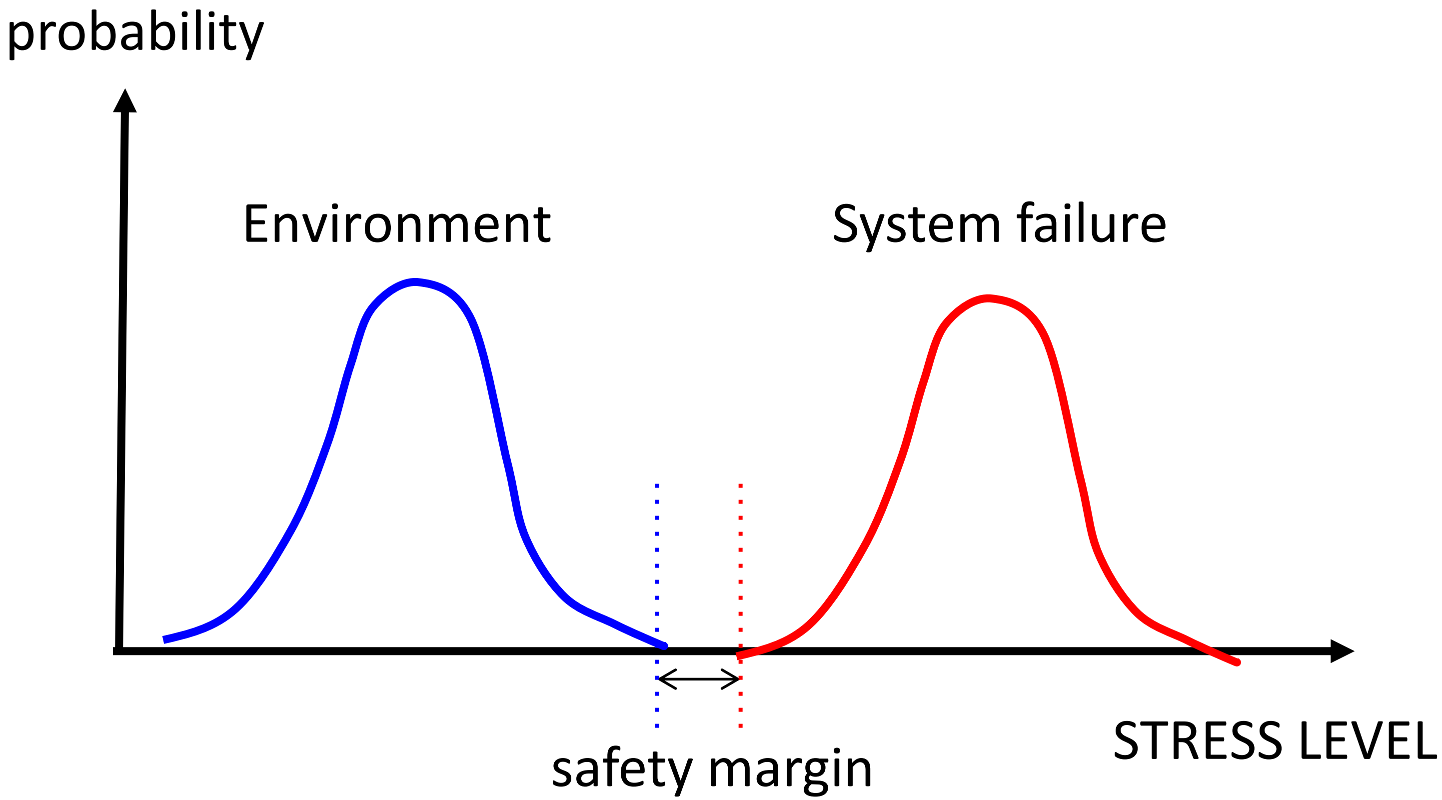


FIGURE 6.1. Envelope for Twelve Measured Vibration Response Spectra Within a Zone.

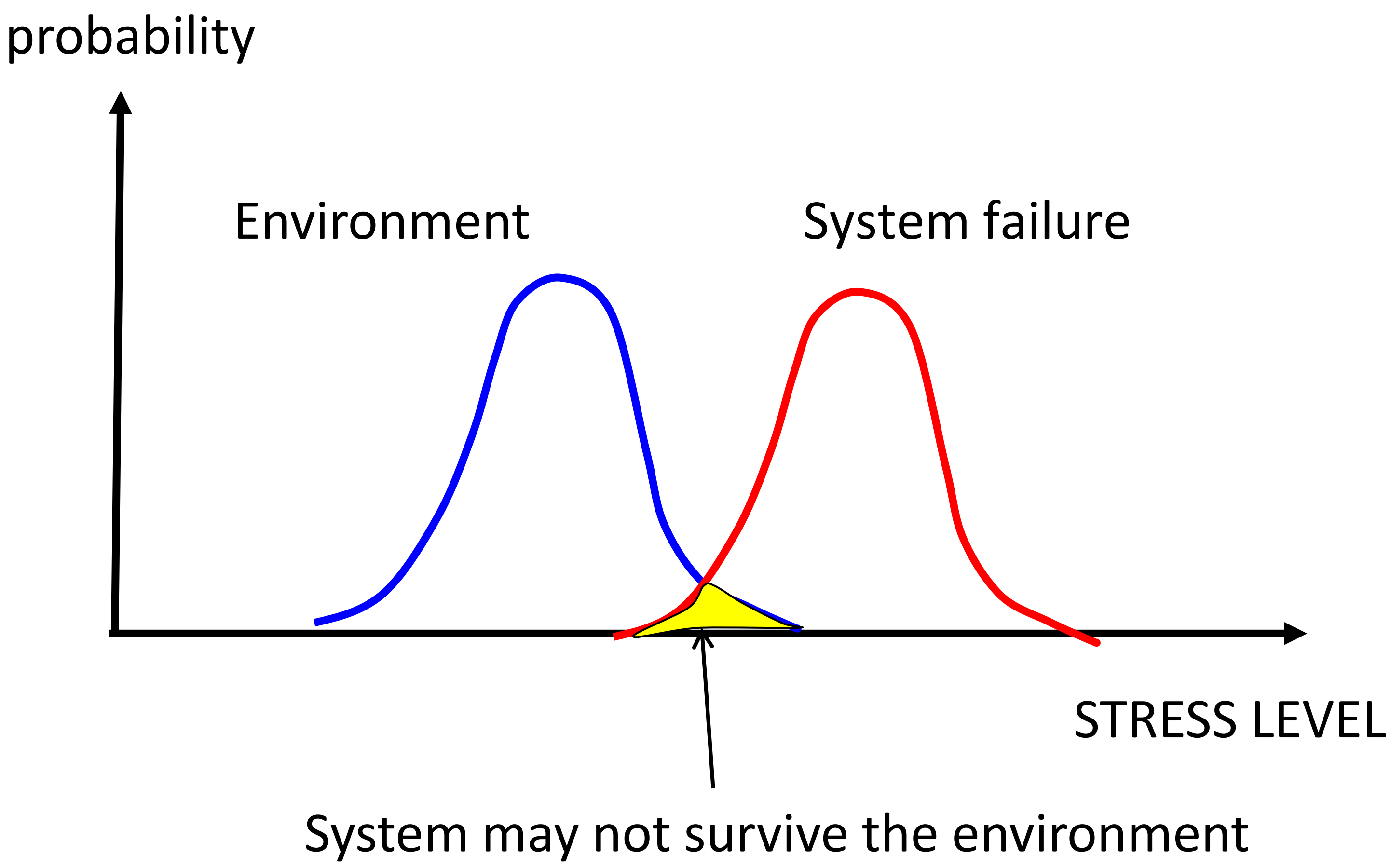
From NASA-HDBK-7005 MARCH 13, 2001

2.10 Margins

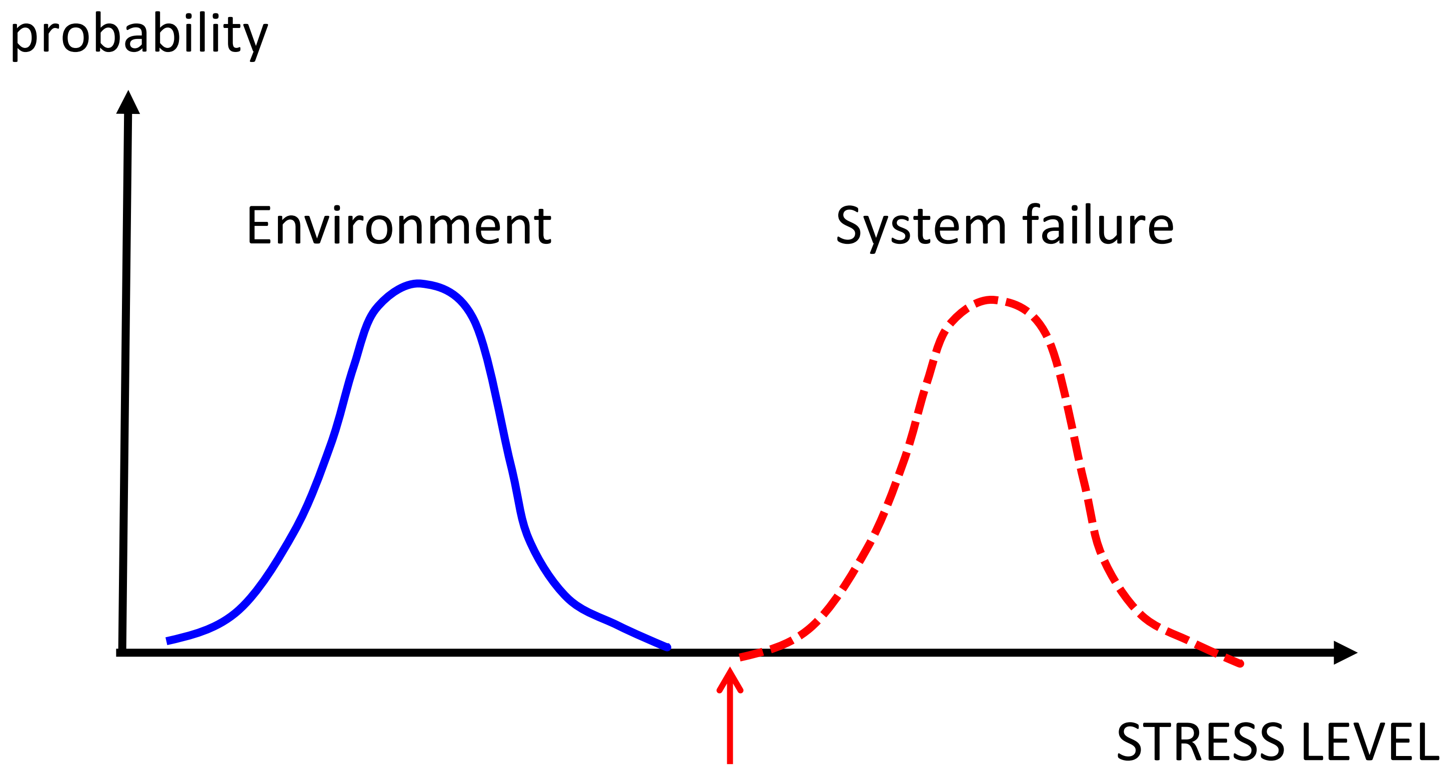


System can survive the environment

2.10 Margins

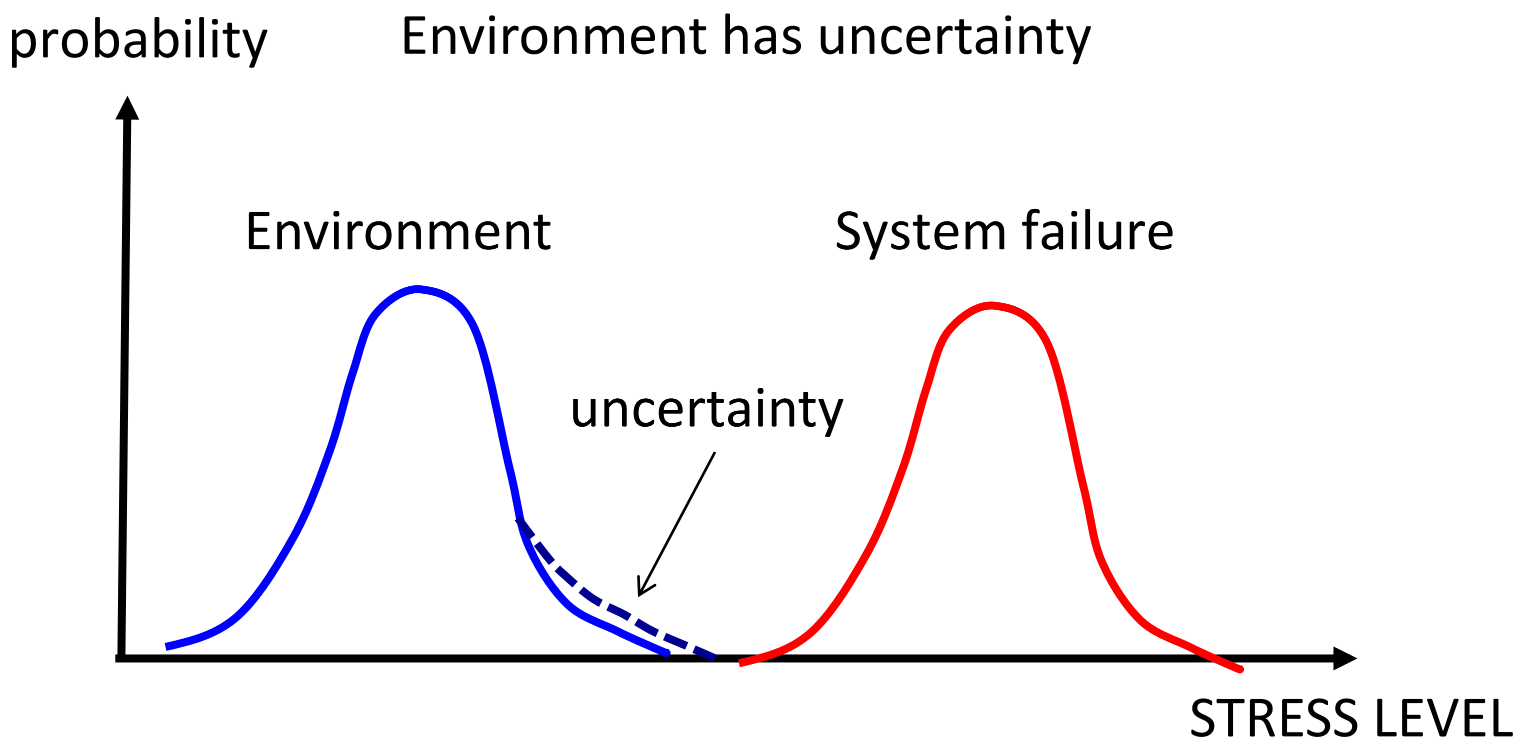

probability
Environment
System failure
STRESS LEVEL
System may not survive the environment

2.10 Margins

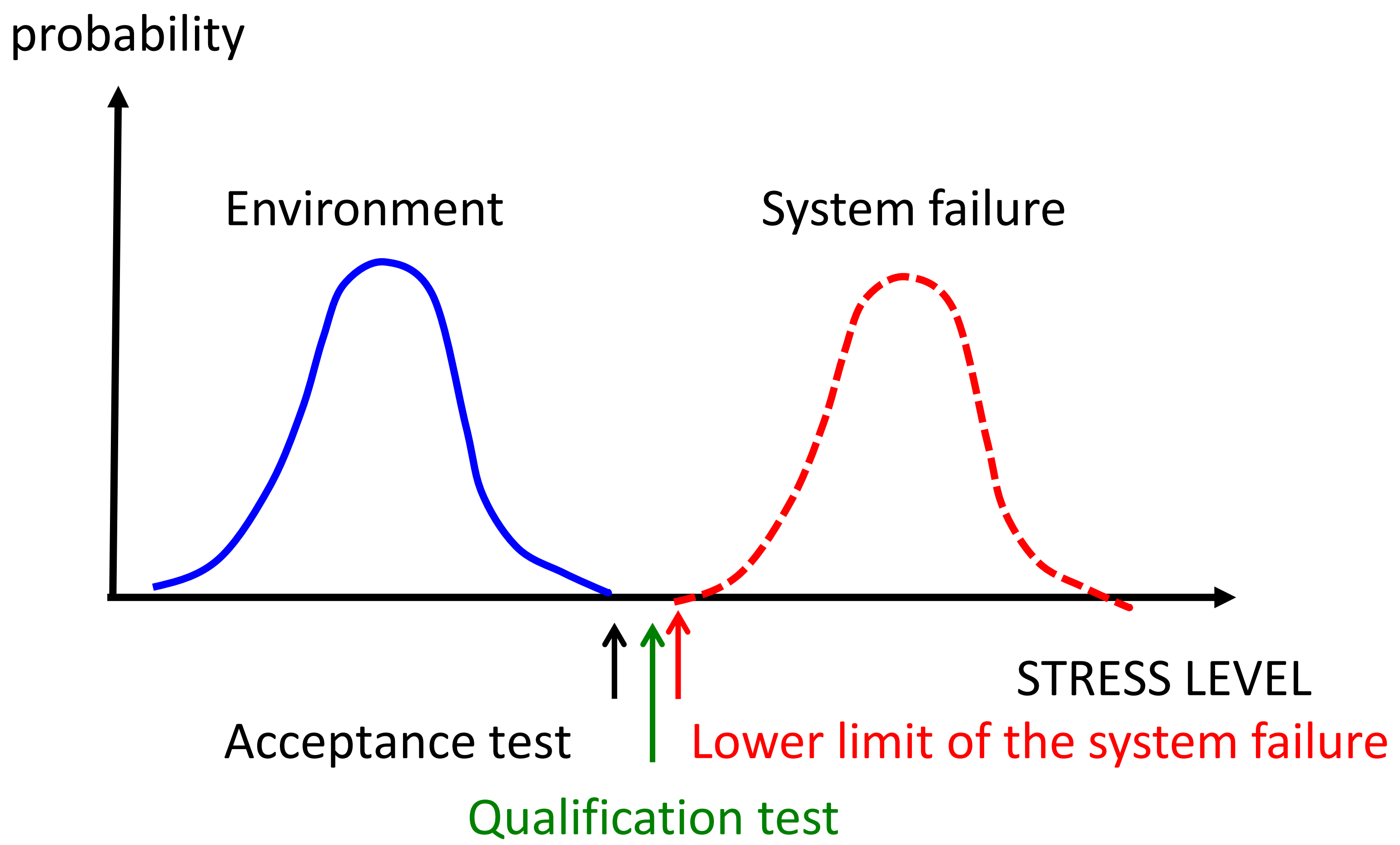


We don’t know the lower limit of the system failure

2.10 Margins


probability
Environment has uncertainty
Environment
System failure
uncertainty
STRESS LEVEL

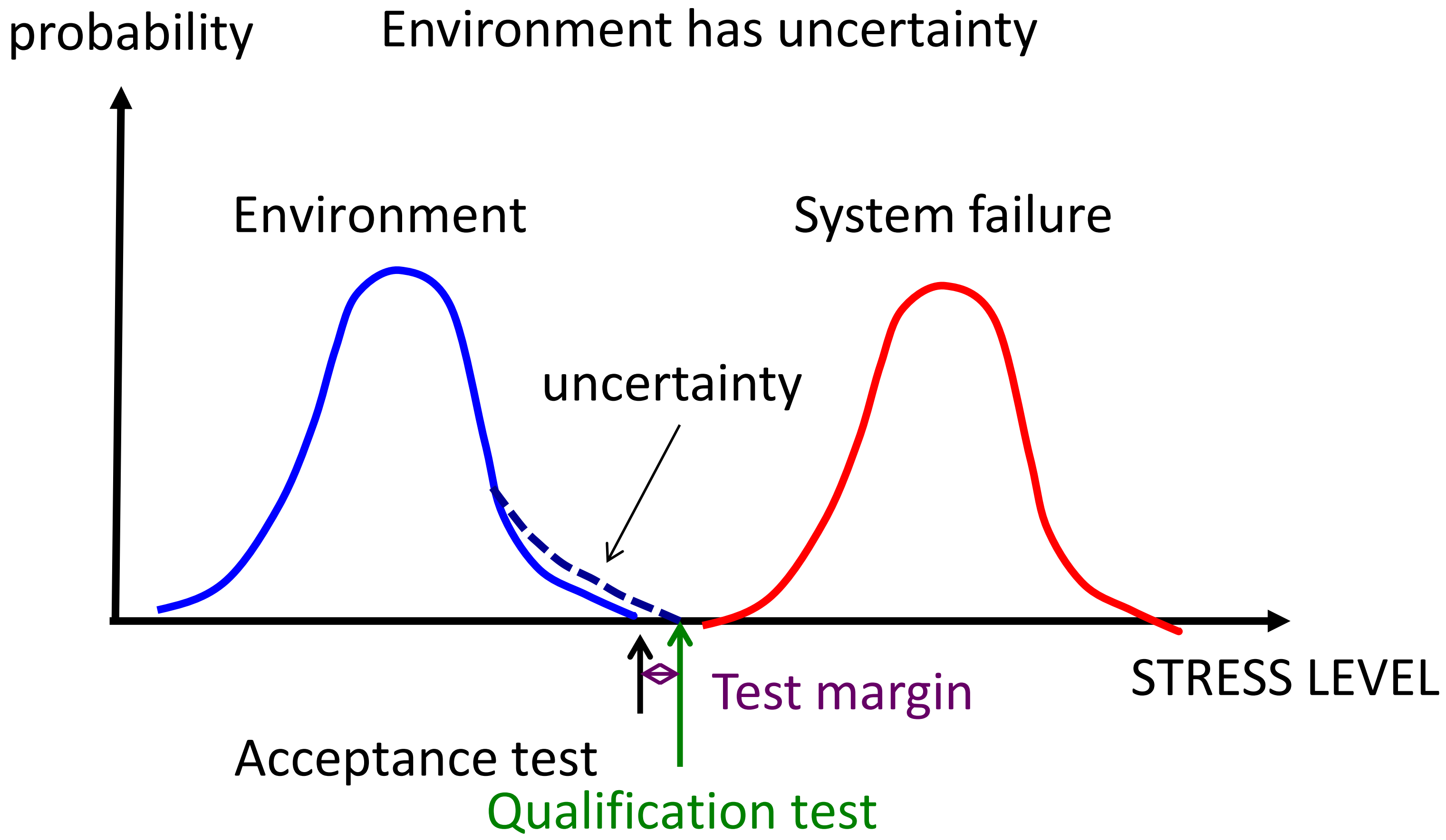
2.10 Margins



Make sure system survives at the test level

At least the system is OK up to the qualification test level

2.10 Margins



Test at the level higher than the predicted maximum to show that the system is OK even if something unpredicted happen

3. Testing

3. Testing

3.1 Test categories

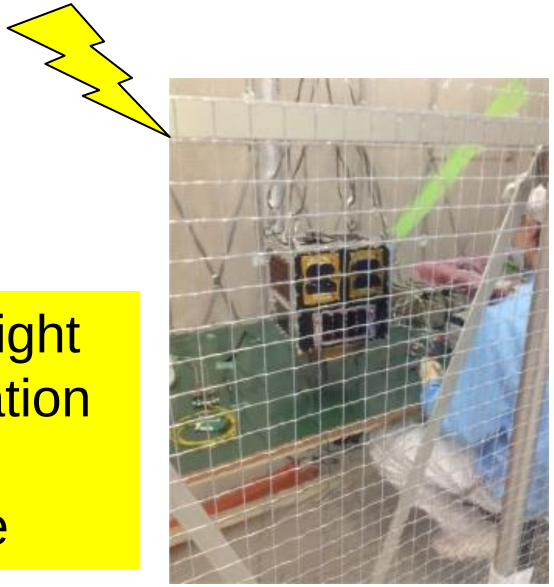
- Functional Test
- Measurement Test
- Environment Test

3. Testing

3.2 Functional Test (ex. End-to-End Test)

- Check the hardware and software work according to the requirement (similar to demonstration)

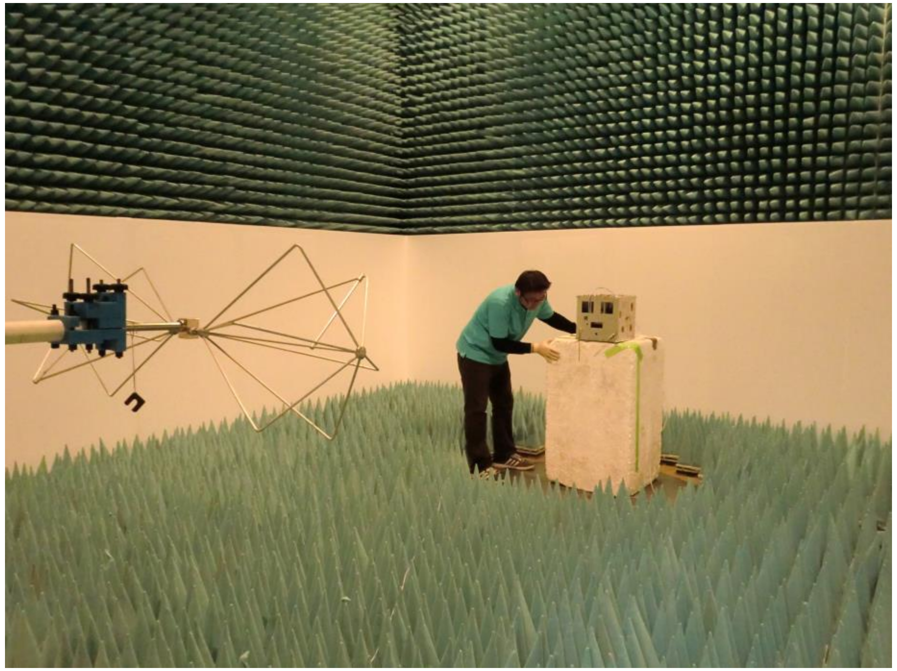
•Communication with satellite flight model using the real ground station
•Complete mission simulation
•Thorough test of flight software



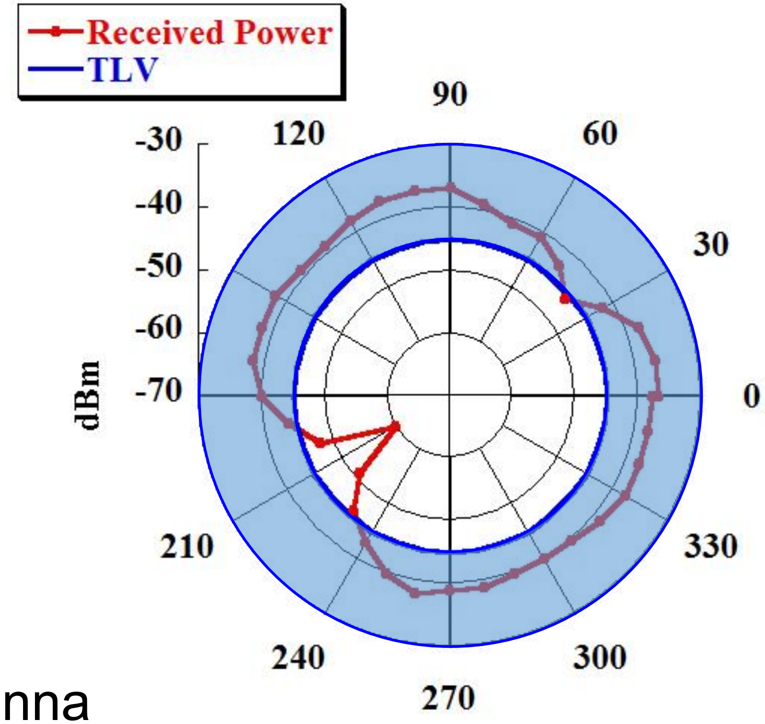
3. Testing

3.3 Measurement Test (ex. Antenna Pattern Measurement)

- Compare the measurement results to the requirement



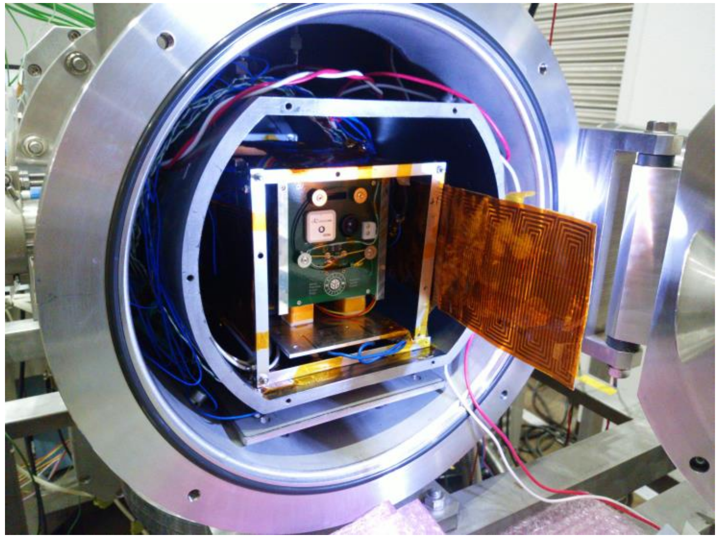
Measure the radiation pattern of the antenna



3. Testing

3.4 Environment Test (ex. Thermal Vacuum Test)

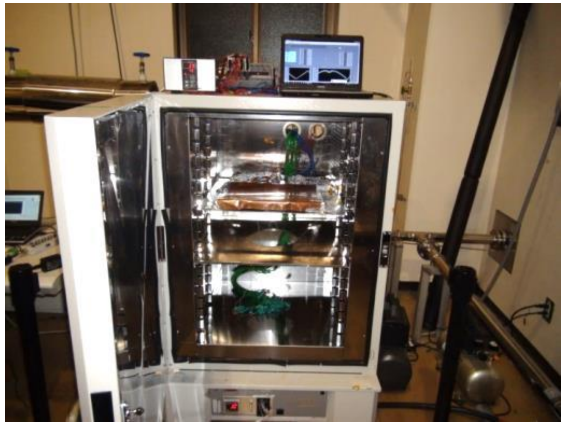
- Check whether the hardware can withstand the environmental stress
  - Inspection after the test
  - Measurement before and after the test
  - Functional demonstration during the test

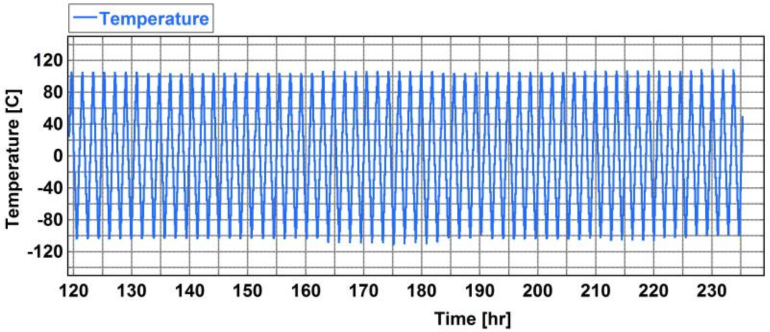


Confirm that the hardware can function at the minimum and maximum temperatures in orbit

3.5 Environment Test (ex. Thermal Cycle Endurance Test)

- Check whether the hardware can withstand the environmental stress
  - Inspection after the test
  - Measurement before and after the test





Confirm that the hardware can survive repeated cycles of hot and cold temperature

3. Testing

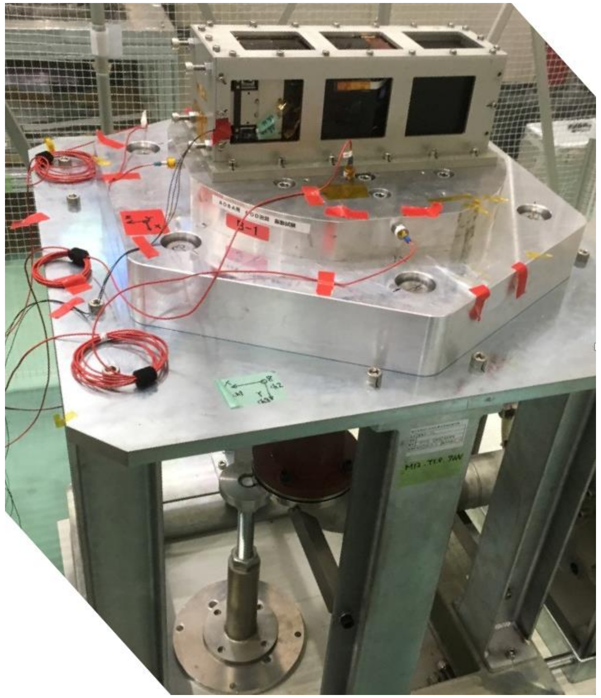
3.6 Environment Test (ex. Vibration Test)

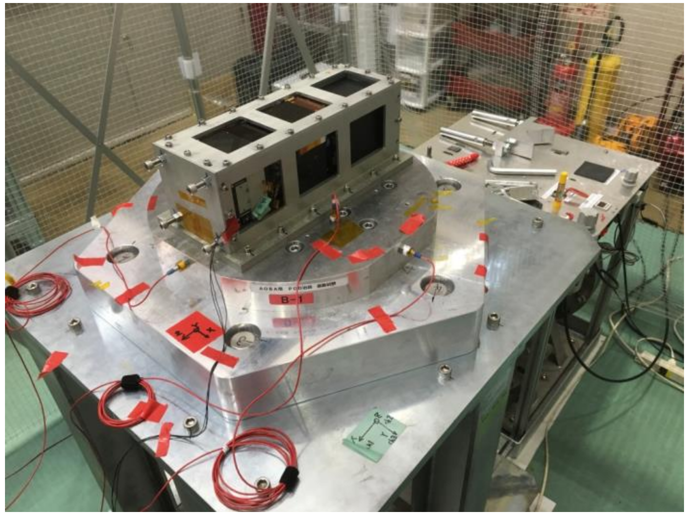
- Check whether the hardware can withstand the environmental stress
  - Inspection after the test
  - Measurement before and after the test

Confirm that the hardware can survive mechanical vibration during launch

3.7 Environment Test (ex. Shock Test)

- Check whether the hardware can withstand the environmental stress
  - Inspection after the test
  - Measurement before and after the test





Confirm that the hardware can survive mechanical shock caused by pyro-devices onboard a rocket

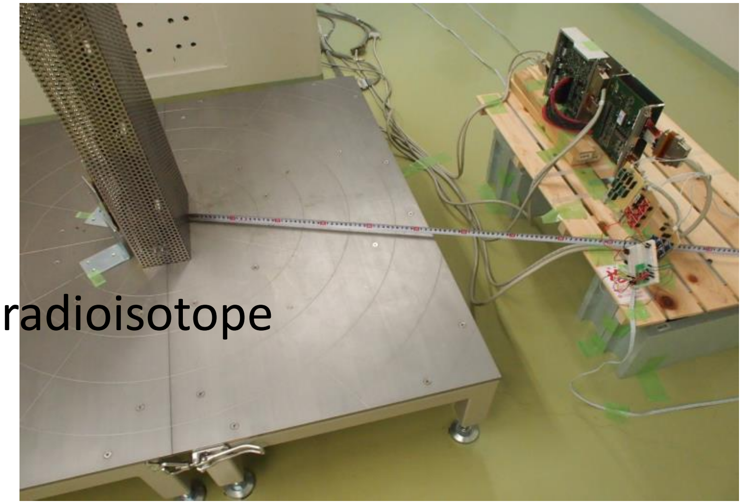
Not required for KiboCube

3. Testing

3.8 Environment Test (ex. Total Ionization Dose Test)

- Check whether the hardware can withstand the environmental stress
  - Inspection after the test
  - Measurement before and after the test
  - Functional demonstration during the test

Device under test



Co^{60} radioisotope

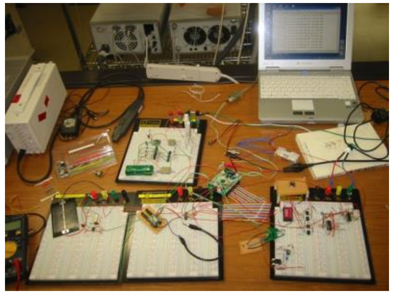
Confirm that the hardware (electronic parts) can survive ionizing radiation

3.9 Test model

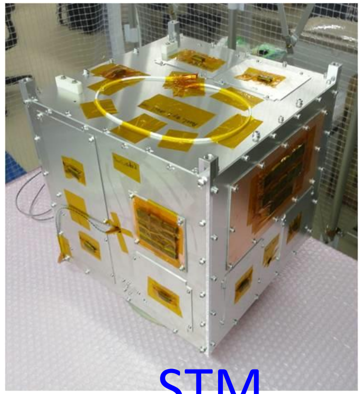
- Bread Board Model (BBM)
- Structure Thermal Model (STM)
- Engineering Model (EM)
- Qualification Model (QM)
- Proto-Flight Model (PFM)
- Flight Model (FM)

Don't fly (BBM, STM, EM, QM)

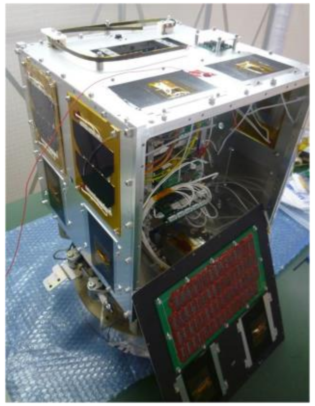
These model may exist also for each component



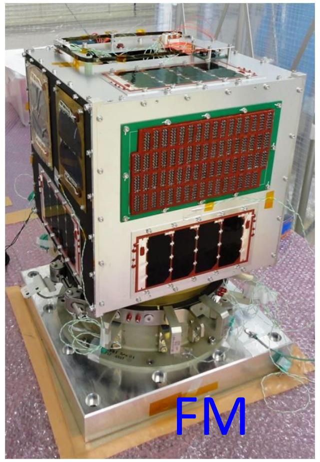
BBM



STM



EM



FM

3. Testing

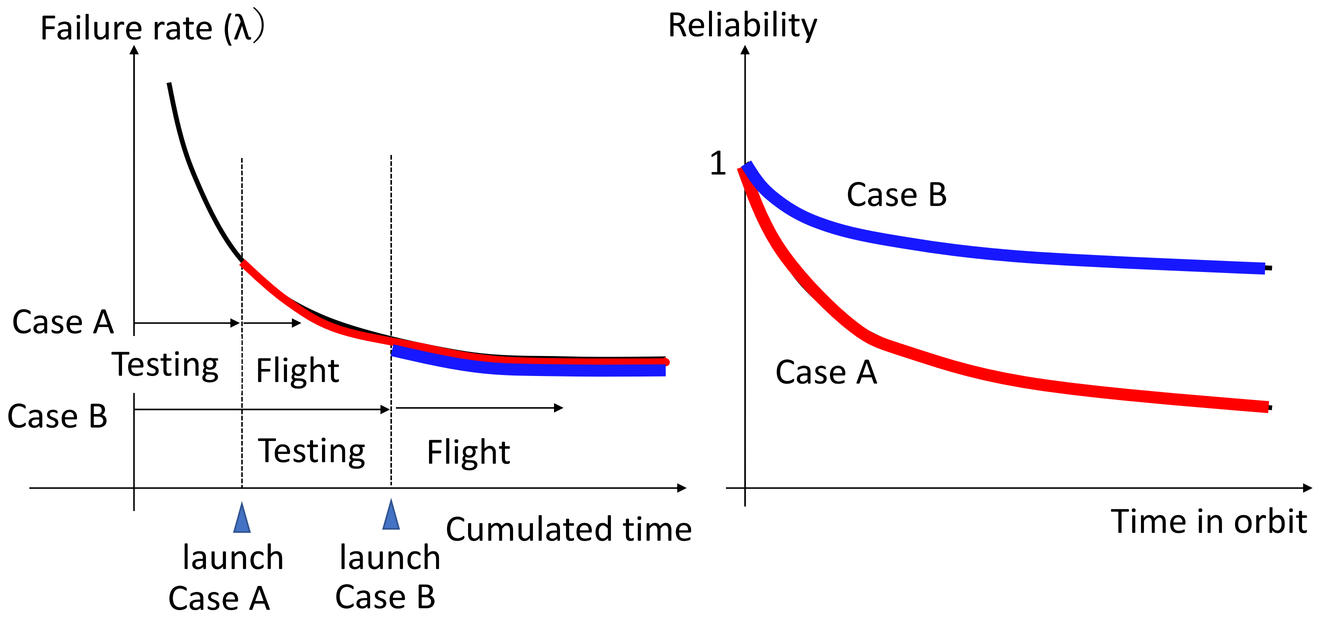
3.10 Typical full approach of 1U CubeSat

- BBM (Breadboard Model)
  - Check functionality and interface
- EM (Engineering Model)
  - Carry out QT (MPE + margin)
  - Also serve as the flight spare
- FM (Flight Model)
  - Carry out AT (MPE)

3.11 How much do we test before launch?

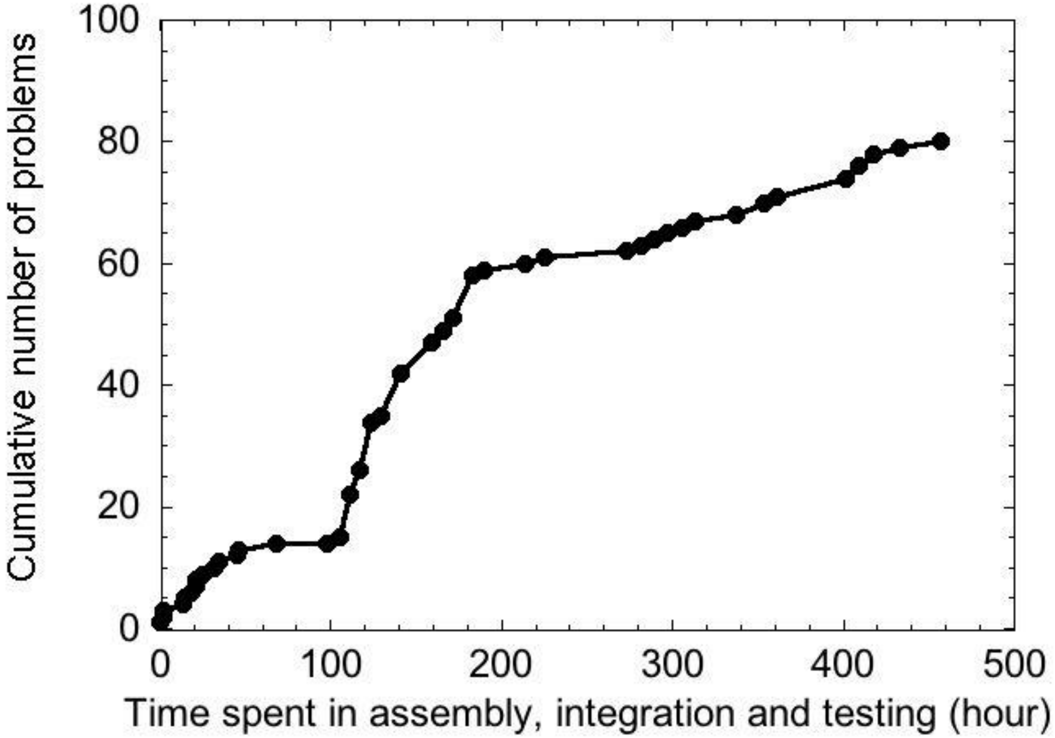
$$R(t) = \exp\left(-\int_0^t \lambda(t')dt'\right)$$

- Reliability, R(t): Probability that the satellite survives until time t from the launch (t=0)
- Failure rate, λ(t): Rate of failure occurrence per unit time
- Failure rate decreases as you find defects in the test and fix them
- The more you test before the launch, the more reliable in orbit



3.11 How much do we test before launch?

HORYU-IV cumulative number of failures against cumulative testing time of Engineering Model



- You find many defects at the beginning of tests, but the pace slows down
- You have to stop the test at some point
- When to stop?
    - After finishing the minimum things you have to do (see the two references)
    - If you have extra time, continue until you hand over your satellite

4. What test do we have to do?

4. What test do we have to do?

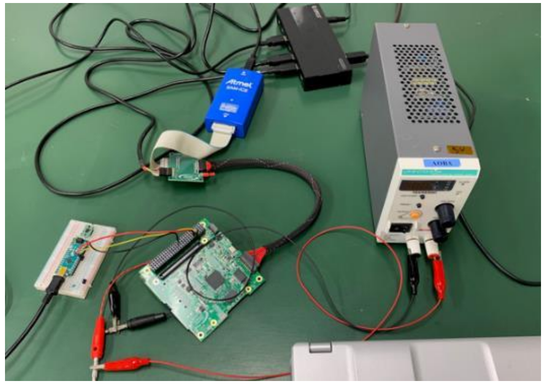
4.1 Test items

1. Electrical interface test
2. Functional test
3. EMC test and End-to-End simulation test
4. Deployment test
5. Launcher/Spacecraft interface test (fit-check)
6. Thermal test
7. Vibration test

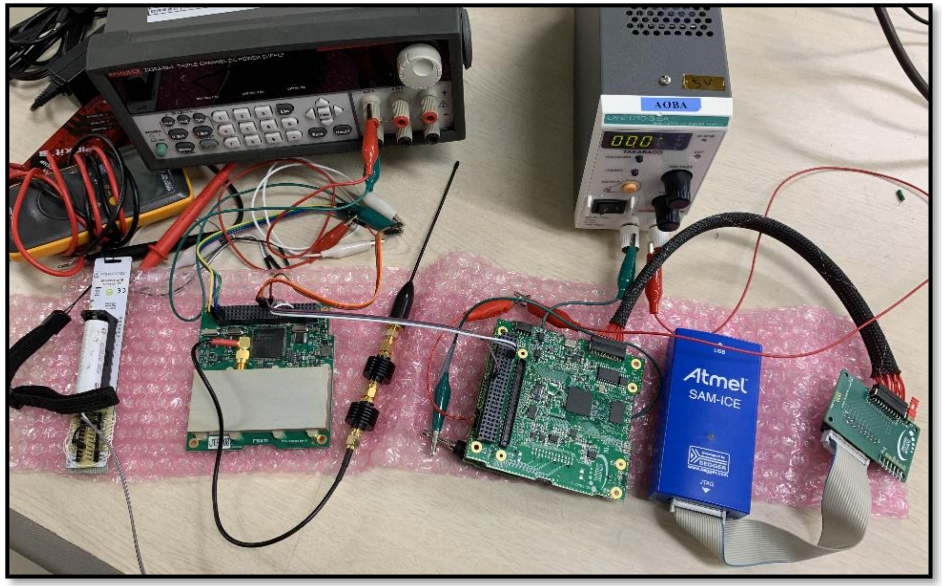
4. What test do we have to do?

4.2 Electrical interface test

- Each component may work fine. But it may not work if it is connected with others



+



4. **What test do we have to do?**

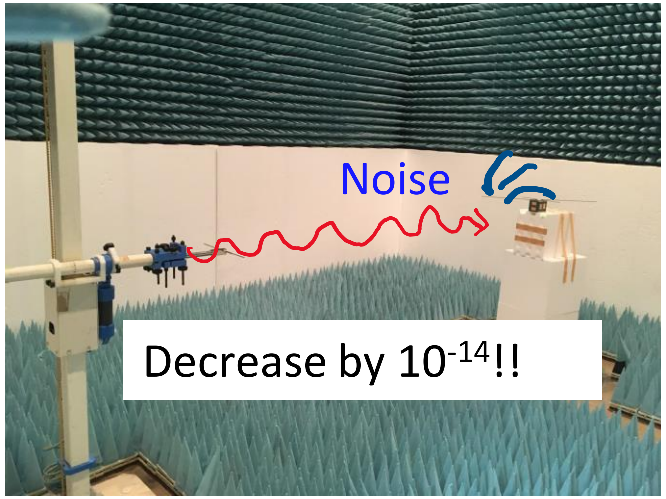
4.3 Functional test

- Make sure the satellite works in laboratory before you move to the environment tests

4. What test do we have to do?

4.4 EMC test and End-to-End simulation test

- Make sure your ground station (GS) can communicate with your satellite
  - Send command uplink from GS
  - Satellite does its job
  - Receive data at GS
  - Do these processes via radio wave in air
- Electromagnetic noise inside the satellite may interfere with the satellite radio receiver

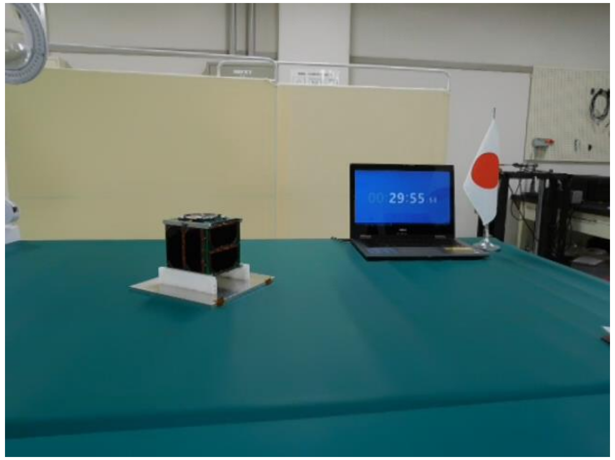


4.5 Deployment test

- Failure of antenna (UHF/VHF) deployment leads to DOA (Dead on Arrival)
- Make sure the antenna can be deployed in the worst condition
- Make sure the antenna deployment timing complies with the safety requirements
  - More than 30 minutes after ISS release

Antenna deployment in very cold temperature

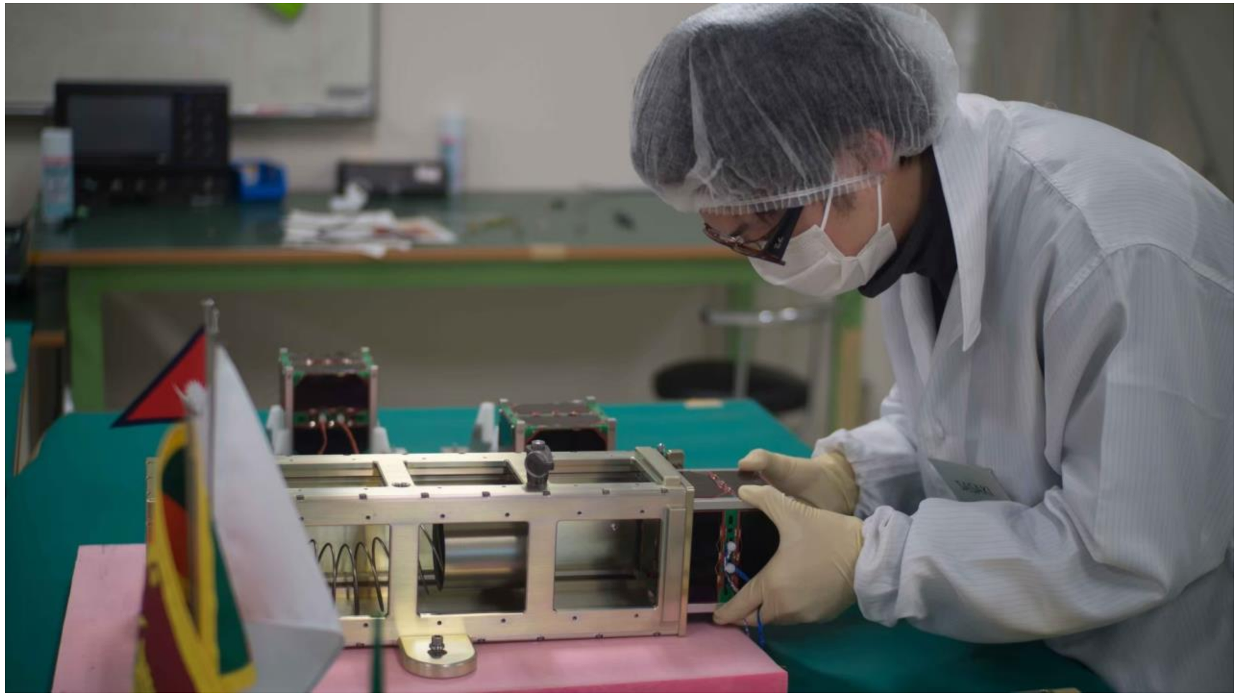
30 mins delay of antenna deployment after ISS release



4. What test do we have to do?

4.6 Launcher/Spacecraft interface test

- Make sure your CubeSat fit into the POD
- The structure may be skewed after full assembly



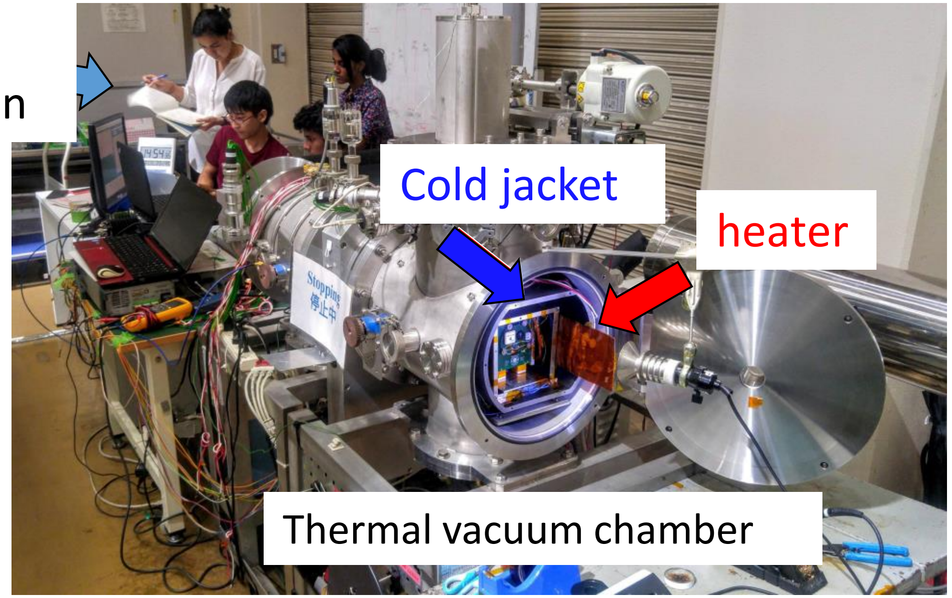
Fit check

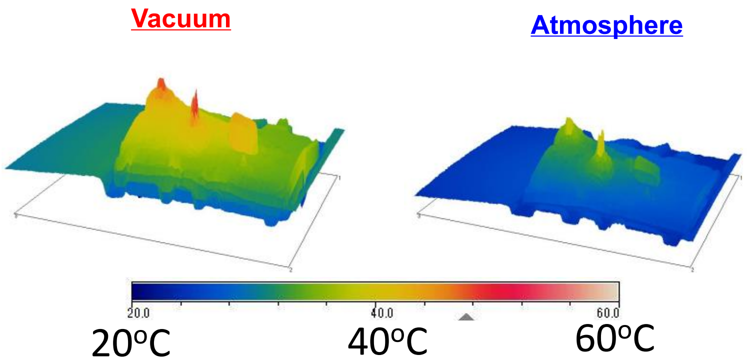
4. **What test do we have to do?**

4.7 Thermal test

- Check the satellite works in
  - Vacuum
  - Hot temperature
  - Cold temperature
- Check that the satellite can survive hot/cold temperature cycles
- Do the mission simulation in flight representative environment

Satellite operation





Temperature distribution on PCB

4. What test do we have to do?

4.8 If you don't have a thermal vacuum chamber

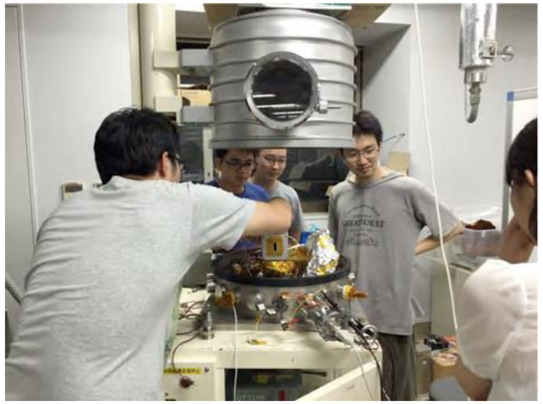
Industrial oven (make hot and cold in atmosphere)

Check that the satellite works at

- Hot temperature
- Cold temperature

+

Vacuum chamber



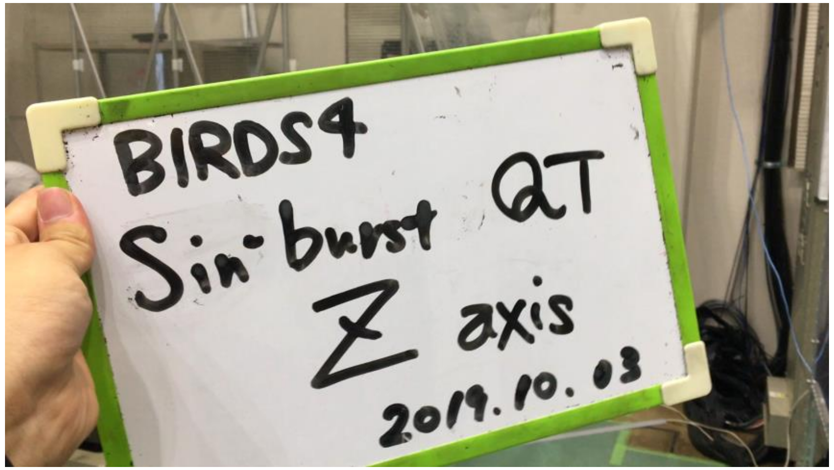
Check that the satellite works in

- Vacuum

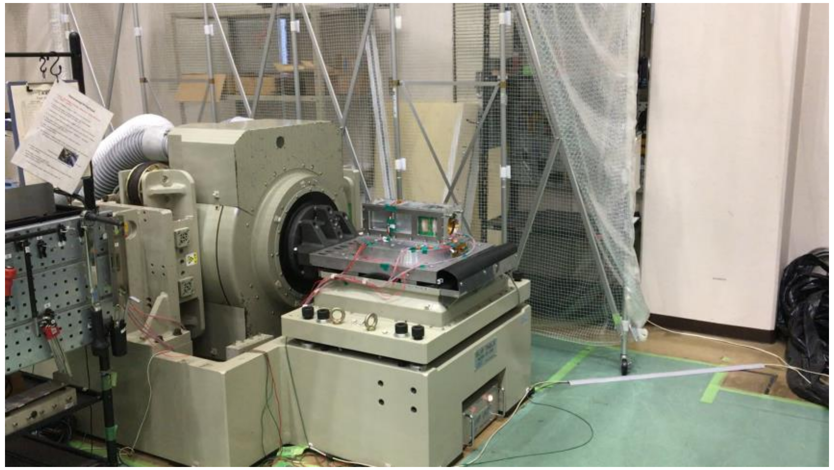
4.9 Vibration test

- Check no loose bolts
- Check no broken glass
- Check no antenna deployment
- Check no anomaly

Sin-burst (low frequency)



Random vibration (up to 2kHz)



4.10 Do we need to do radiation test?

- Most likely, you don't have access to radiation test facilities
- Choose components/parts that have flight heritage
  - When you buy a component, ask the vendor
- Make sure that you can finish the mission objectives in a short time (several months)
  - Do not expect that COTS (commercial-off-the-shelf) electronics parts to last a long time (>3 years) in orbit
- Design the satellite to recover from malfunction due to single events
  - Turn-off and on if the satellite is hung up
- Many CubeSats work in orbit without doing radiation tests

5. Conclusion

5. Conclusion

- Building a satellite is not your purpose
- The satellite must work in orbit
- Testing will improve the odds of mission success
- Do not over-test, but do all the tests you have to do

Thank you very much.

[Disclaimer]
The views and opinions expressed in this presentation are those of the authors and do not necessarily reflect those of the United Nations.