KiboCUBE Academy

Lecture 23

CubeSat Mission Assurance

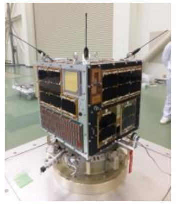
Kyushu Institute of Technology

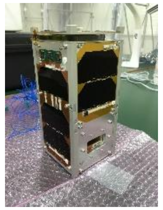
Laboratory of Lean Satellite Enterprises and In-Orbit Experiments

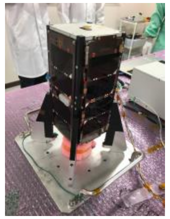
Professor Ph.D. Mengu Cho

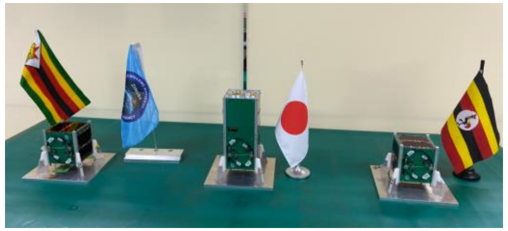
This lecture is NOT specifically about KiboCUBE and covers GENERAL engineering topics of space development and utilization for CubeSats.
The specific information and requirements for applying to KiboCUBE can be found at:
https://www.unoosa.org/oosa/en/ourwork/psa/hsti/kibocube.html

0. Lecturer introduction









Mengu Cho, Ph.D.

Position:

(*since 2018)
(up to 2022)

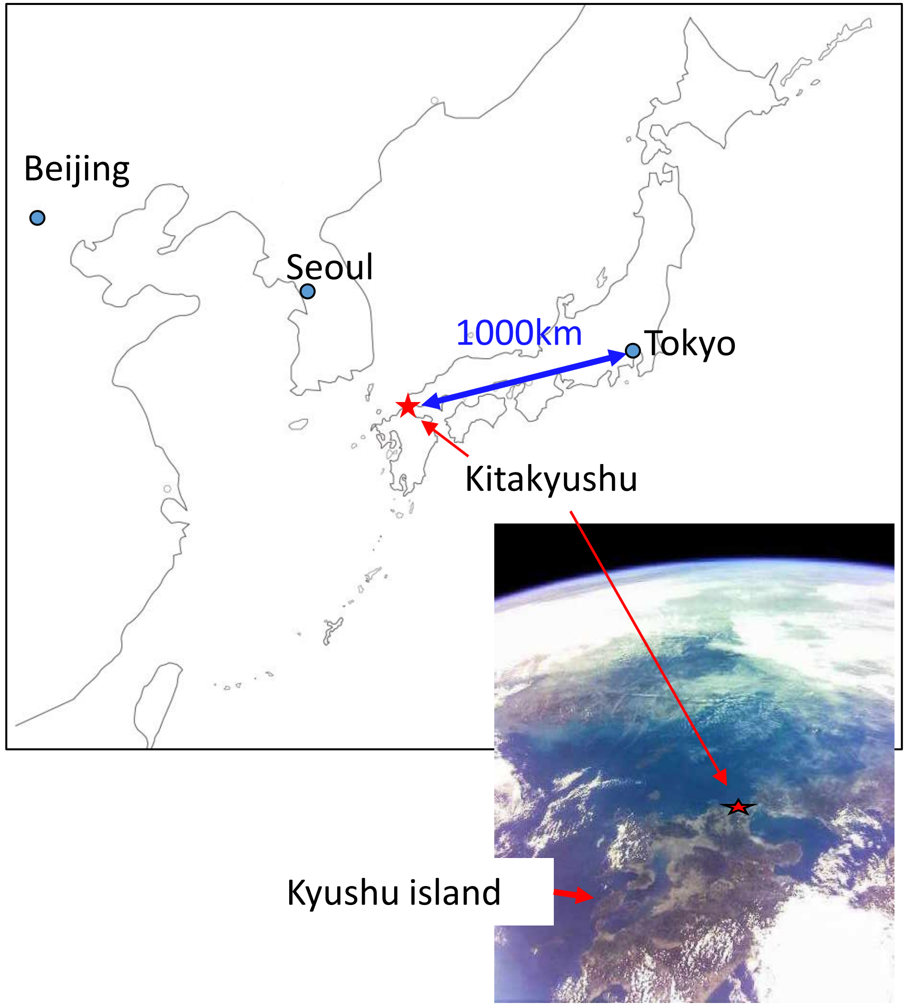
2004 - Professor, Department of Space Systems Engineering*
Director, Laboratory of Lean Satellite Enterprises and In-Orbit Experiments **
Kyushu Institute of Technology, Japan
2021 – Visiting Researcher, Chiba Institute of Technology, Japan
2014 - Visiting Professor, Nanyang Technological University, Singapore
2013 - Coordinator, United Nations/Japan Long-term Fellowship Programme, Post-graduate study on Nano-Satellite Technologies (PNST)

Research Topics:
Lean Satellite, Spacecraft Environment Interaction

0. Lecturer introduction

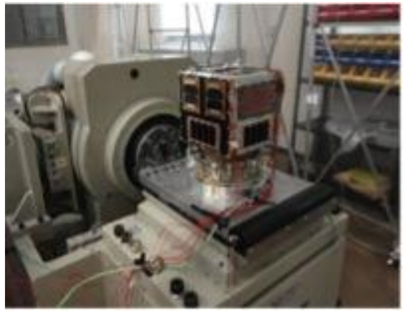
0.2 Kyushu Institute of Technology (Kyutech)

- A national university founded in 1909
  - 4,200 Undergraduate students
  - 1,300 Graduate students
  - 360 Faculty members
  - Engineering, Computer science, Life-science
- Located in the Kitakyushu region
  - Population of more than 1million

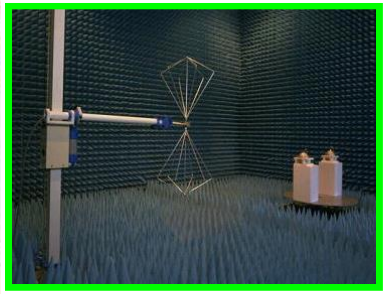


0.3 Center for Nanosatellite Testing

To be capable of doing all the tests for a satellite up to 50cm, 50kg



Vibration



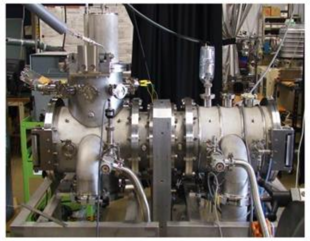
EMC & Antenna pattern

Pressure & Leak

Thermal vacuum

Assembly & Integration

α&ε measurement



Thermal vacuum

Thermal cycle

Shock

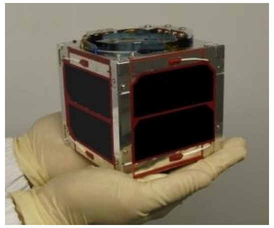
Outgas
(ASTM E595)

Tested more than 70 satellites since 2010 including satellites from overseas (e.g. Egypt, Costa Rica, Singapore, Malaysia, Vietnam, Thailand, etc.)

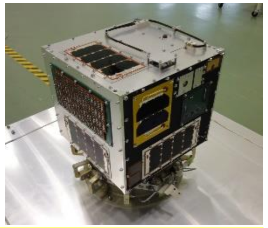
Space Development and Utilization Award (JAXA president award), 2022

0. Introduction to Kyutech

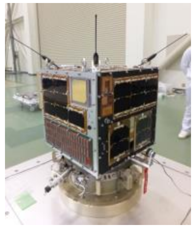
0.4 Kyutech Satellite Heritage



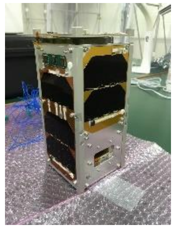
HORYU-1 (1U)
2006-2010
Not launched



HORYU-II
2010-2012
Launch 2012/5/18



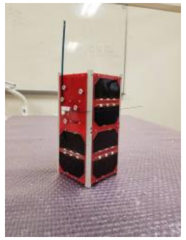
HORYU-IV
2013-2016
Launch 2016/02/17



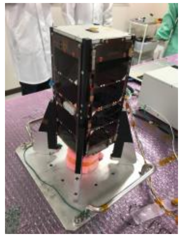
AOBA VELOX-III
2014-2016
ISS Release 2017/01/19

BIRDS-I constellation
2015-2017
ISS release 2017/07/07

BIRDS-II constellation
2016-2018
ISS release 2018/08/10



SPATIUM-I
2016-2018
ISS release 2018/10/06

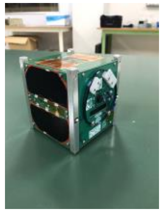


AOBA VELOX-IV
2016-2018
Launched 2019/01/18

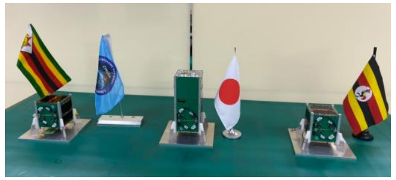
BIRDS-III constellation
2017-2019
ISS release 2019/04/18

BIRDS-IV constellation
2018-2020
ISS release 2021/03/14

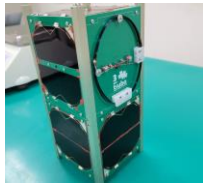
KITSUNE
2019-2021
ISS release 2022/03/24



FUTABA
2018~2021
ISS release
2022/08/12



BIRDS-5J, -5Z, -5U
2020-2022
ISS release 2022/12/2



MITSUBA
Launch failure
2022/10/12

Satellite name
Satellite development period
Launch/ISS release date

World's No.1 academic small satellite operator since 2018

(Bryce Space Technology report on SmallSats by the Numbers)

Contents

1. Introduction

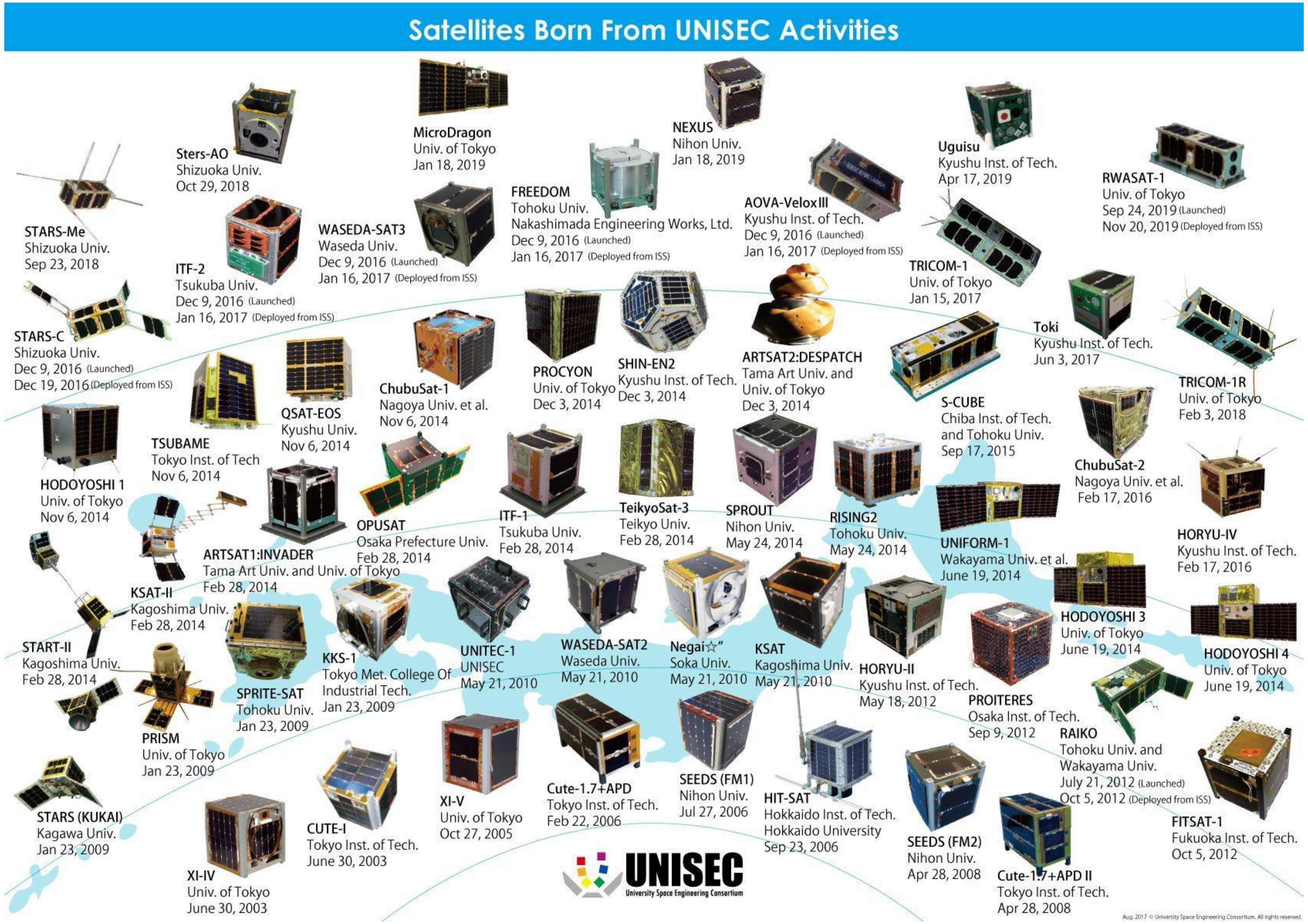
1. Introduction

1.1 University satellite projects in Japan

- UNISEC-Japan consists of
  - 36 Universities and research institutions
  - 49 organizations
  - 636 student members, and
  - 262 individual and 19 cooperate members, and
  - alumni members (based on Apr. 13, 2021).
- UNISEC-Japan members maintain cooperative relationships in conducting practical space development and utilization.

1. Introduction

1.1 University satellite projects in Japan



1. Introduction

1.2 UNISEC's Lean Satellite Mission Assurance Activities

- In 2020, members of UNISEC-Japan utilized the time that became available due to the pandemic in
  - Remote sessions on lessons learned from university satellite projects in UNISEC (University Space Engineering Consortium) JAPAN in 2020
  - Survey on the lessons learned of mission assurance
    - Sponsored by JAXA
  - Report (439 pages!) on
    - Analysis about the success and failure cases of domestic micro and nano-satellite projects and their causes.
    - Extraction of requirements for mission assurance of micro and nano-satellites.

JX−PSPC−530505

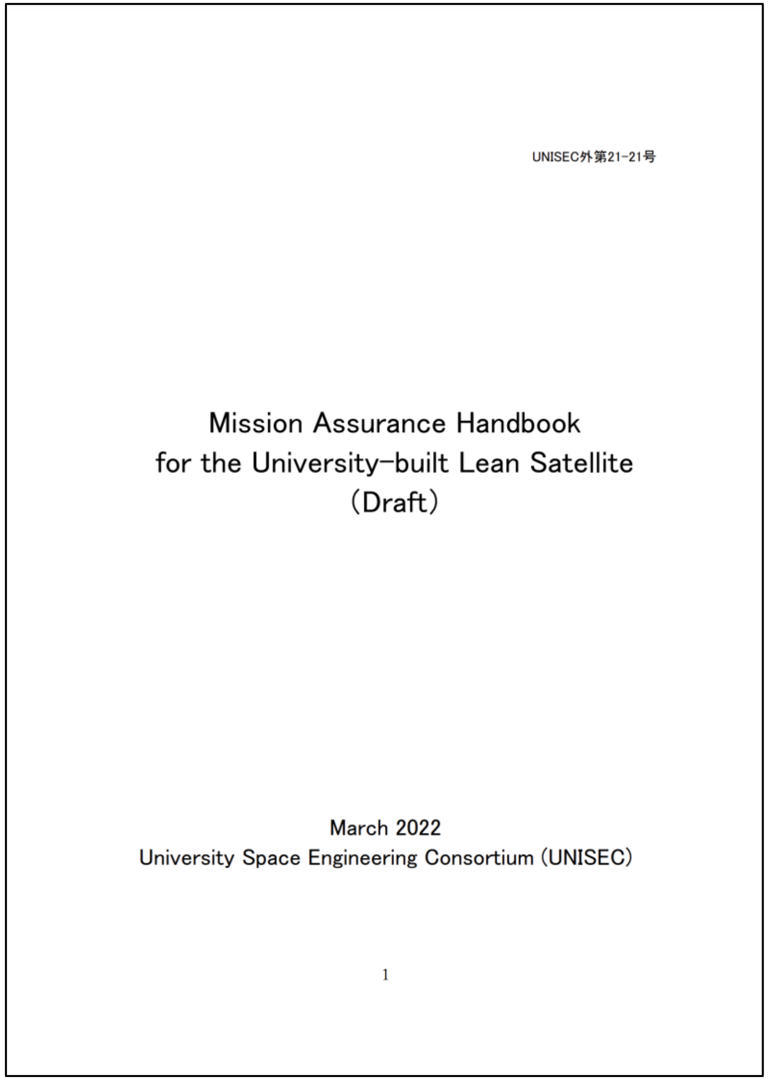
2020年度　超小型衛星の成功率向上に向けたJAXA知見を
活用した支援方法の調査検討
成果報告書

2021年3月26日
特定非営利活動法人大学宇宙工学コンソーシアム
(UNISEC)

1. Introduction

1.2 UNISEC's Lean Satellite Mission Assurance Activities

- Following the activities in 2020, in 2021 UNISEC members worked on
  - Mission assurance handbook for university-based lean satellites
    - Further analysis of the failure cause by conducting intensive interviews with the persons in charge of the projects.
  - Based on the activities, the "Mission Assurance Handbook for the University-built Lean Satellite" was published in March 2022.


UNISEC外第21-21号

Mission Assurance Handbook
for the University-built Lean Satellite
(Draft)

March 2022
University Space Engineering Consortium (UNISEC)

1

2. Lessons Learned and Root Causes

2. Lessons Learned and Root Causes

2.1 Lessons Learned

- Examples of lessons learned is available at KiboCUBE Academy: Season 2: On-demand Pre-recorded Lectures
- **Lecture#21 Lessons Learned from CubeSat Missions (KiboCUBE Academy S2 Pre-recorded）**
- https://www.youtube.com/watch?v=Vae0cisgI50

Satellite	Lessons
3U CubeSat	Difficult to assemble, promised unnecessary things in safety review suppressing the time for system test
1U CubeSat	Beginner satellite, mistake in solar cell bypath diode, poor schedule management
2U CubeSat	Communication was too difficult for mechanical engineering students, Poor schedule management
50kg satellite	Frequent power reset erasing the attitude control history
50kg satellite	Shortage of knowledge in power system. Relied too much on a vendor
7kg satellite	Optimistic confidence in design without verification leading to frequent hang-up due to single-event-latch-up
1U CubeSat	Satellite design not consistent with mission requirement
1U CubeSat	Internal noise prevents uplink success. Rely on single person for communication test

2. Lessons Learned and Root Causes

2.2 Root causes

- Interviewed the key person of each satellite project to analyze the root causes
- Many common causes among different cases
  - Poor schedule management
  - Team structure
  - Inconsistency in requirements
  - Improper verification planning
  - Wrong strategy to avoid total satellite loss
  - Insufficient full system end-to-end test
  - Difficulty in assembly, integration and testing
  - Poor understanding of the rationale behind the design
  - Others

3. Mission Assurance

3. Mission assurance

3 .1 What is mission assurance?

- Mission assurance
  - A series of activities to identify the factors in design, making, operation of the satellite, etc. that will hinder mission success, and to eliminate or decrease the effects of such factors.
- University satellite is categorized as a “Lean Satellite”
  - a satellite that utilizes non-traditional, risk-taking development and management approaches – with the aim to provide the satellite value to the customer and/or the stakeholder at low-cost and with a short time to realize the satellite mission[1].
- Lean satellites tolerate risk, but still need to achieve mission success as much as possible
  - “Failure is not an option” nor “Failure is accepted”

- [1] “Definition and Requirements of Small Satellites Seeking Low-Cost and Fast-Delivery”, Edited by Mengu Cho and Filippo Graziani, International Academy of Astronautics, 2017, Code ISBN/EAN IAA: 978-2-917761-59-5

3. Mission assurance

3 .2 Mission Assurance Handbook for the University-built Lean Satellite

- Target satellite projects at universities and polytechnic-colleges in Japan
  - Not only the first project of the universities, but also the second and later projects
- Summary of points to be kept in mind of faculty members and students to improve the mission success rate
- Organized in the order of project life-cycle
- Published and available online
- Much of the content is still applicable to satellite projects in new space companies and/or non-Japanese organizations

3 .2 Mission Assurance Handbook for the University-built Lean Satellite

- Use your smartphone and capture the QR code below

https://ma.unisec.jp/wp-content/uploads/2023/06/ma_handbook_ver2.0_en.pdf

3. Mission assurance

3 .3 Mission Assurance Handbook for the University-built Lean Satellite

Contents

1. Introduction
2. Project management
3. Mission definition
4. Conceptual design
5. Detail design
6. Production
7. Testing
8. Operation
9. Post-operation
10. Sustainability of university satellite program

Ordering according to project life-cycle (items 2–9)

If you missed the last page

From now on, the page title number is the ones used for the mission assurance handbook.

3. Mission assurance

2.1 Project management (schedule management)

- First projects often fail. Improper schedule management due to a lack of satellite project experience
- Very little time spent in system tests
- Guideline for the project milestones until satellite delivery

FM: Flight model, EM: Engineering model
STM: Structure Thermal model
BBM: Bread-board model
MDR: Mission Definition Review
PDR: Preliminary Design Review
CDR: Critical Design Review
FRR: Flight Readiness Review

Review	Time	Milestone
FRR	D	Satellite delivery
↑ FM, 6 month ↓	D-1 month	FM hardware and software complete. Finished hardware testing. Basic GS software is complete
	D-3 month	All FM hardware components delivered and ready for FM system assembly
CDR	D-6 month	Finished EM testing and confirmed that the satellite functions as a system
↑ EM, 7 month ↓	D-10 month	All EM hardware components delivered and ready for EM system assembly
PDR	D-13 month	Finished proof of concepts. Confirmed that the missions are feasible. Finished EM design and start procurement
MDR	D-A* month	Determined what missions to be done

A* depends on each satellite project

3. Mission assurance

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Verify that the mission is doable using hardware such as BBM (bread board model). Give up missions if their feasibility is uncertain

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3 months. Wait for EM hardware delivery. Many things to do such as structural analysis, STM vibration test, Software analysis using BBM. Secure the test facilities

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A* depends on each satellite project

4 months. Verify interface compatibility from the components delivered. Significant amount of time in trouble shooting. Learn testing. For the first satellite, EM vibration test will not end in one time.

3. Mission assurance

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A* depends on each satellite project

3 months. Takes unexpected amount of time due to design change from EM to FM. No guarantee that FM works because EM worked. Need to do functional checks components one-by-one when delivered. Secure the test facilities for FM. Make Plan-B.

3. Mission assurance

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A* depends on each satellite project

2months. Repair of FM may be necessary if defects are found. The test schedule may change day-by-day.

3. Mission assurance

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A* depends on each satellite project

Concentrate on flight software bug finding by End-to-End long duration testing. Needs to judge whether the bug is actually fixed or not.

3. Mission assurance

2.2 Project management (project team organization)

- Not possible to have all the talents necessary for the projects by students alone. Need to find solutions to fill the shortage:
    1. Procurement
    2. Collaboration with external people
    3. Expect students to grow
- Even for 1 or 2, the requirements for the procured or outsourced items must be made by the team
- Keep persons familiar with the satellite design for operation
    - Need to finish the project life cycle (from kick-off to operation) in 3 years
- The principal investigator (faculty member)
    - Responsible for keeping the student motivation
    - Responsible for securing the communication channels for the external assistance

3. Mission assurance

2.3 Project management (Lean philosophy)

- Activities are categorized three ways

1. Value-adding activity
   - Improve satellite reliability
   - Enhance attitude control accuracy
   - Others
2. Non-value added but necessary activity
   - Safety compliance
   - Frequency license
   - Space activity act
   - Others
3. Pure waste (Muda)
   - Searching for tools
   - Others

- **Eliminate the waste and do the non-value added but necessary activity efficiently**
  - Many wastes in “moving” and “waiting”
  - Have the office, the work room, the testing room and the ground station in one building

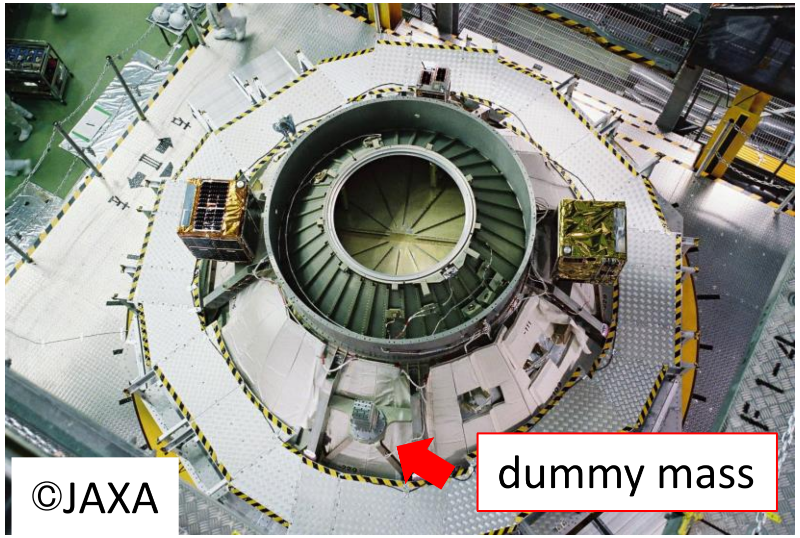
3. Mission assurance

2.4 Project management (Frequency coordination and licensing)

- Frequency coordination and radio licensing application may result in
  - Change of satellite design
  - Change of satellite missions
  - Delay of satellite delivery
  - Giving up satellite missions
  - Limits on satellite operation
  - Others
- Work often concentrates on specific members
  - Multiple members need to monitor the progress
  - Understand human nature
    - Understand the work is necessary. But deadlines approaching motivates work.

2.5 Project management (Compliance with safety requirements)

- Non-compliance with the safety requirements may lead to serious delays of the schedule
- In the worst case, the satellite is not launched
  - Dummy mass will go instead of your satellite
- At the end of conceptual design and detailed design, list-up the issues related to safety requirements and confirm with the launch provider
- Agree with the launch provider on the safety requirement verification methods that can be done with **the minimum effort**
  - The safety verification is necessary, but a non-value adding activity
  - Do more value-adding activities such as mission assurance



2.6 Project management (Document management)

Why do we need documents?

a) Regulatory works（safety, frequency, space activity acts, etc.)

b) Communication within the project (needed during development, test, and operation)

c) Traceability to prepare for the anomaly/failure investigation during the operation

d) Knowledge transfer

e) Sharing knowledge and know-hows with other projects

f) Source data to write journal papers or thesis

- Important for mission assurance: (b), (c), (d)
- Important for anomaly/failure during operation
- Important for reflecting the lessons learned to the next project
- Very few students like document works
  - One idea is to link these activities with students bachelor or master thesis

3. Mission assurance

3.1 Mission definition phase (feasibility)

- **Know the limits** when you define the missions
  - Team talents and skills
  - Budget
- **A professor is not a God**
  - Doesn’t know everything to judge the mission feasibility
  - Open mind to suggestion/comments/assistance by others

- 3-axis stabilization from the first satellite?
- High-speed communication by mechanical students?

3.2 Mission definition phase (Mission Success Criteria)

- Minimum success
  - Things to be achieved even if the satellite has problems
- Full success
  - Things to be achieved when the satellite works as expected
- Extra success
  - Something more than expected in addition to the full success
- Use quantitative indicators as much as possible, especially for minimum and full success
- You may need to change the criteria as the project proceeds, but
  - Examine whether the meaning of the entire project can be achieved (i.e., Can we satisfy the project stakeholders?)
- When you discuss a design change
  - Examine whether the minimum success criteria can be achieved
- Try to achieve the minimum success criteria as soon as the satellite is deployed into orbit

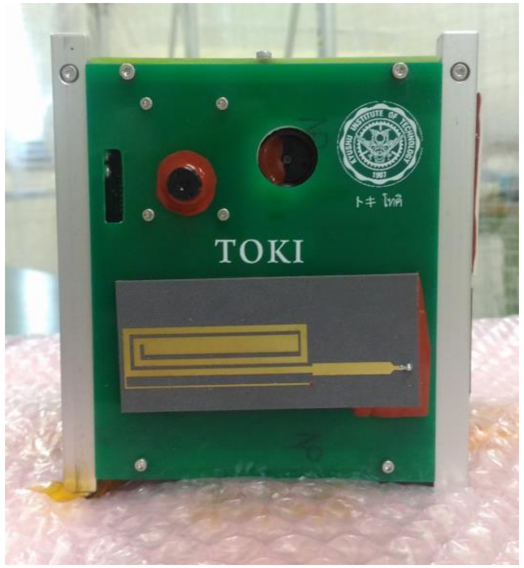
3. Mission assurance

3.3 Mission definition phase (Mission Scenario or Concept of Operation)

- Consider each mission scenario (Concept of Operation, ConOp)
  - Command from the ground station
  - Functional flow inside the satellite
  - Downlink to the ground station
- Useful for functional analysis and derivation of design requirements
- Make a budget table
  - Communication
  - Power
  - Attitude (pointing)
  - To be revised as the project goes on and improve the accuracy
- If the mission has no margin at the mission definition phase, that mission is not possible

4.1 Conceptual design phase (requirement management)

- Check consistency between the mission requirements and the design requirements
  - Design should satisfy the mission requirements
  - No design requirement that doesn't fit to the mission requirements
- External review by experienced experts is effective
- Open-mind to external suggestions



4.4 Conceptual design phase (Verification plan)

- No use of a design that cannot be verified
- Doable verification plan

List of minimum test items for an ISS-released CubeSat

Test Item	EM(QT)	FM (AT)
Electromagnetic Compatibility	R	N*1
End-to-End mission simulation	R	N*1
Electrical interface	R	R
System function	R	R
End-to-End long-time operation	N	R
Deployment	R	R
Fit Check	R	R
Thermal	R	O*3
Random Vibration	O*2	R

R: Required
O: Optional
N: Not necessary

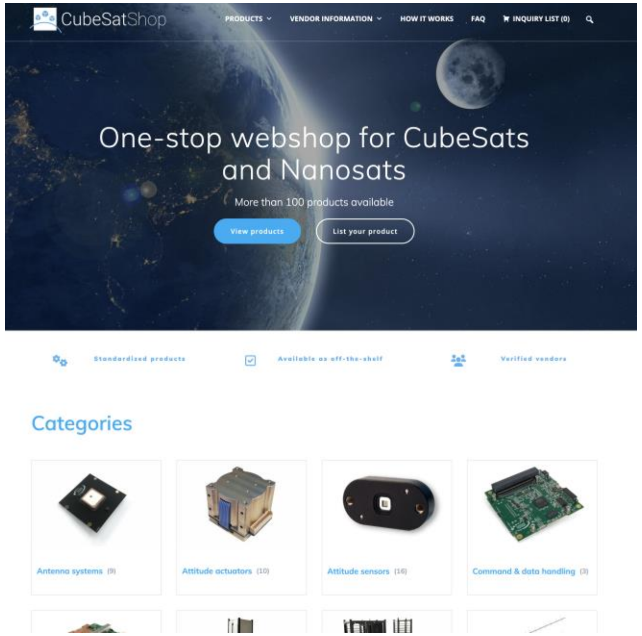
*1 Included in End-to-End long-time operation test
*2 Depends on needs of each satellite
*3 The exposure to high/low temperature may be required for safety requirements verification

3. Mission assurance

5.1 Detailed design phase (Parts and component selection)

- Do not decide the vendor by price and performance only
  - Availability
  - Easiness of handling (clear interface)
  - Good response to repair
  - These points are sometimes more important than size, price, functionality
- The same components without any new development works should be used for 2nd, 3rd satellites
  - Minimize the development work
  - Slight changes may lead to cost increases or longer delivery times
- Joint development with the vendor should aim at transferring all the know-how to the vendor
  - Sustainable supply chain

There are many vendors. But selection must be made carefully.



https://www.cubesatshop.com/

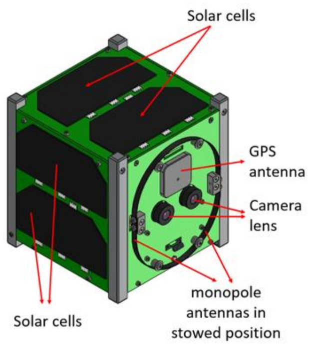
5.2 Detailed design phase (Risk Management, FTA, FMEA)

- Try to minimize the risks based on **priority**
- **External review** is effective to list up the risks with high priority along with the safety issues
- FTA/FMEA are not taught in school
  - Start from the levels students/professors can understand
  - List up any single-point-of-failure and **prioritize** the risks
    - Not only part/components, but also works (wrong command, wrong assembly, etc.)

5.3 Detailed design phase (Die-hard satellite)

- Avoid complete failure (loss of communication with the ground)
- "God PIC", Micro Controller PIC16F877 for power reset
- Battery recharging from an empty condition
- Satellite works w/o battery using solar panel only
- Redundant communication links if volume is available
- Feasible power budget for the minimum function (communication with the ground) even with
    - Loss of attitude control
    - Solar paddle deployment failure
    - Loss of one solar panel
- Verify that the satellite can recover from the power reset
    - Avoid "zombie" state

From Digikey®

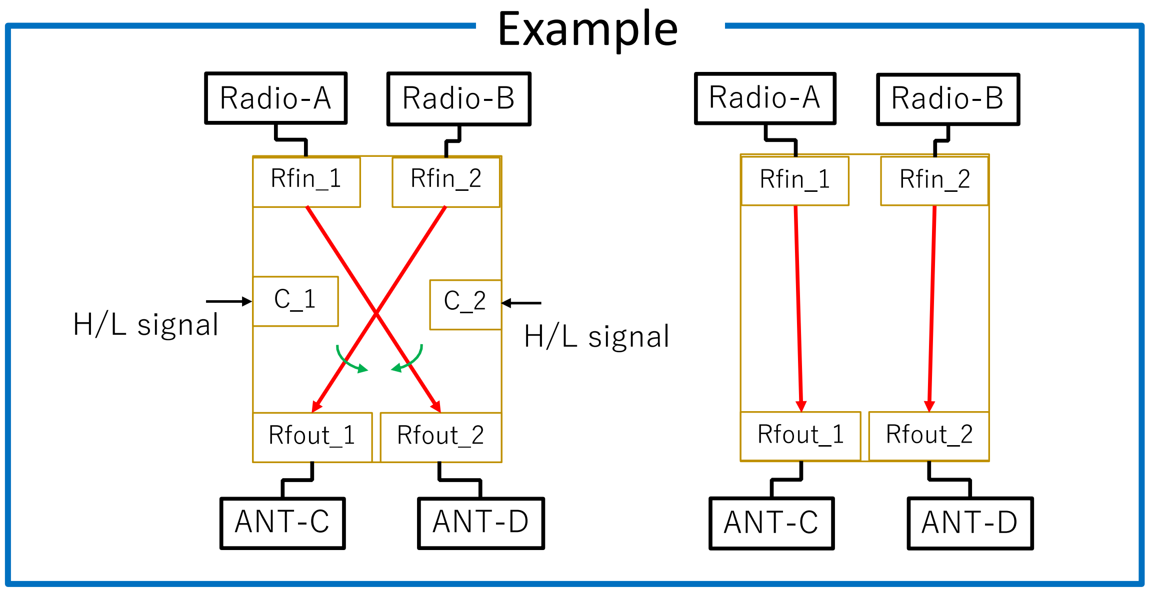


https://www.irasutoya.com/2013/04/blog-post_1022.html

3. Mission assurance

5.5 Detailed design phase (Points to Note in Design Changes)

- When the design change is discussed, evaluate
  - Benefits obtained
  - New risks generated
- Use minimum success and full success as criteria



- Antennas and radios have no flight heritage
  - Improve the reliability of communication
- Risk of RF switch being stuck in the intermediate position (no communication)
- Without the RF switch, communication is possible if one pair of radio and antenna survives

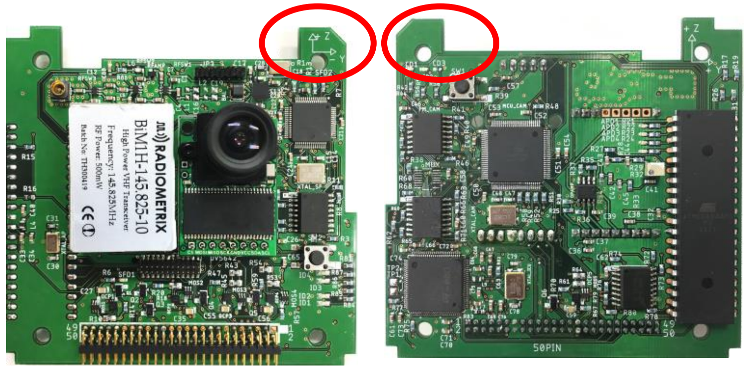
5.6 Detailed design phase (Easy operation)

- Imagine how to execute the mission
- Reflect the lessons learned from the pervious operations
- Stored command (reserved command)
  - Make missions execution possible anywhere in the orbit
  - Do a series of maneuvers
  - Increase the amount of data by downlink to GSs other than Japan
    - Be careful about frequency coordination
- Simple uplink commands
  - Small number of bytes to improve the uplink success rate
- GS software can adopt remote and automatic operation
  - The team size may be significantly smaller during operation due to graduation
- Keep housekeeping data history before power reset
- Keep important parameters before/after reset
  - Control gain of attitude control

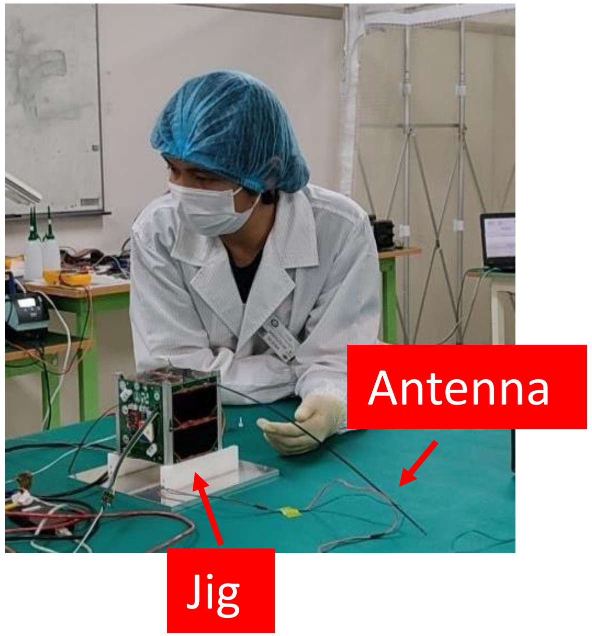
3. Mission assurance

5.7 Detailed design phase (Easy to Assemble, Integrate and Test)

- Reduce the number of fasteners (bolts), harness, connectors, as much as possible
  - Possible causes of workmanship error
- Implement the mitigation against mistake in the design
  - “Being careful” is not a solution
- Save connectors
  - Frequent attach/remove of connectors may cause damage
- External ports to internal processors
- Physical inhibits against antenna deployment
  - You may want to work on the software until the last minutes. But deployment may not be allowed after the final safety review.
- Prepare jigs for the assembly, test, storage.
- Think how to carry a satellite
  - Do not carry a satellite by hand



front back



6.1 Production (Quality control)

- Quality of commercial-off-the-shelf components (COTS) parts are guaranteed by the manufacturer as mass-produced items
  - If an anomaly occurs, most likely due to improper handling after delivery
    - Static electricity mitigation
    - Handling in clean environment
- Individual COTS parts quality may be guaranteed. But the quality of components is not necessarily guaranteed
  - University satellite components are often one-of-a-kind. No established manufacturing processes
  - Even if multiple components are made simultaneously, no guarantee that all the items are good
  - Once a component is delivered, a basic functional test shall be done before it is integrated into the system

6.2 Production (inhouse vs outsourcing)

- The purpose of an education satellite
  - Practice systems engineering and project management
  - Not acquiring handyman skills
- Do not try to save money by making in-house
  - After all, it may end up in schedule delays and cost increases
- Buy quality and time with money
- Some students have good hand skills. But some do not. Relying on student hand skills is risky.

6.3 Production (Compliance with safety requirement)

- Verification of safety requirements in FM stage is critical to pass the safety review
- Agree on safety hazard control methods before FM assembly between the launcher and the satellite
- Need to verify that the control methods were implemented according to the agreement
- Before moving to FM assembly, the team members (especially AIT team) should be aware of what **procedures** they have to follow and what **documents** they need to make
- Good communication between safety officers and AIT team

3. Mission assurance

7.1 Testing phase (Electromagnetic Compatibility Test)

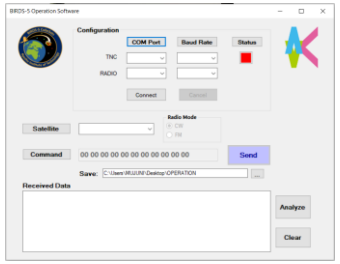
- Because of cold launch, EMC with launchers and other satellites are not important
- Live with self-generated noise
- Verify that the communication link has enough margin
  - Uplink signal level is much higher than the satellite-generated noise floor
  - Confirm before moving to FM

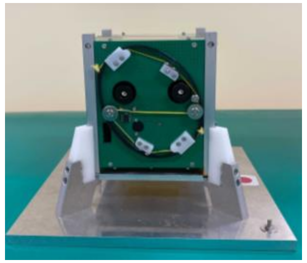
Sensitivity test for uplink success in a shield box

7.2 Testing phase (End-to-End mission test)

- Verify the basic data flow of the main mission
  - Command uplink
  - Satellite mission
  - Data downlink
  - Confirmation of data on GS PC
- Make the details, after confirming that the basic mission can be done

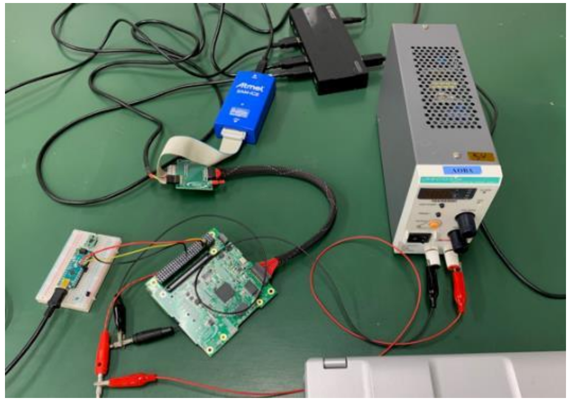
GS PC → GS radio → Satellite → GS radio → GS PC





7.3 Testing phase (Electrical interface test)

- Even if the component works alone, no guarantee that it works in the system
- Before integrating the component into the satellite structure, verify the interface with other satellite components
- **Even if the EM was OK, it does not guarantee that the FM is OK**



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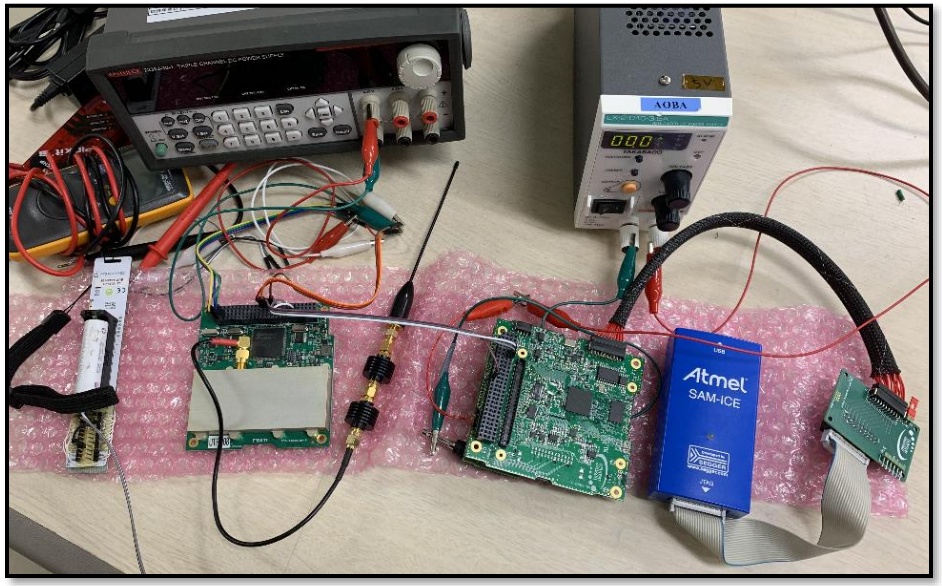


7.4 Testing phase (System functional test)

- Move to FM assembly as soon as the FM components are delivered and start the function tests as an integrated system
- Check the consistency of data sent from the satellite
- Do not move to the environment tests (e.g. vibration, thermal vacuum) before you solve problems
  - Expect many problems to be found. Have enough schedule margin before moving to the environment tests

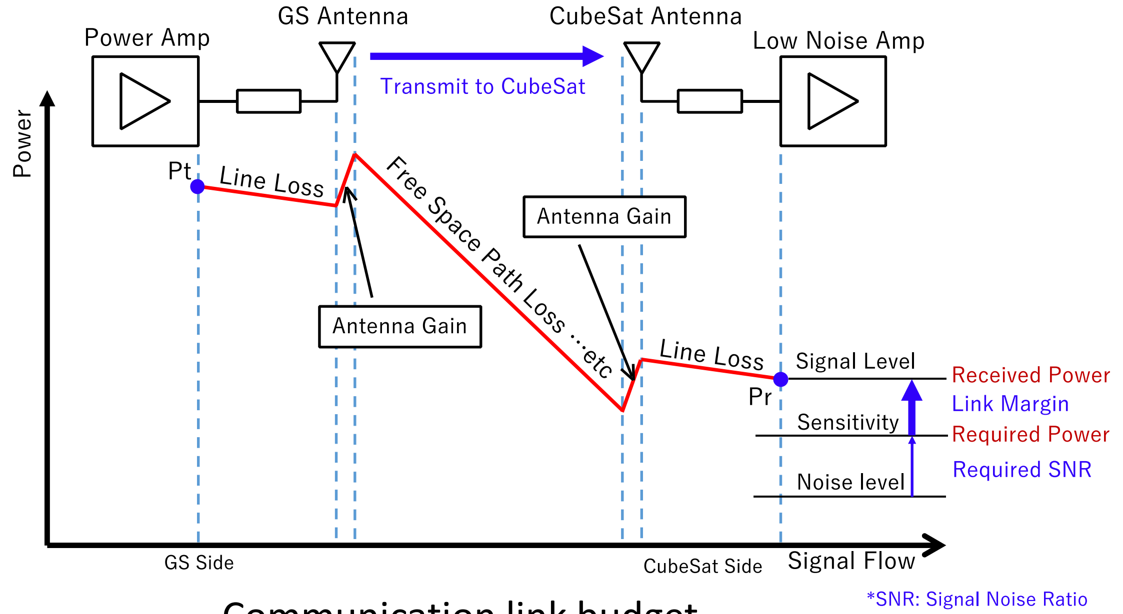
FM system function test

3. Mission assurance

3 .14 Testing phase (End-to-End Long-term operation)

- Finding and fixing bugs of flight software
- Operation rehearsal
  - Critical modes (release, recovery from reset, etc.)
  - Nominal modes (HK data collection)
  - Mission modes
- Link budget confirmation
  - Compatibility with ground station

Line loss and noise level inside the satellite is hard to derive theoretically. Confirm the link budget by testing

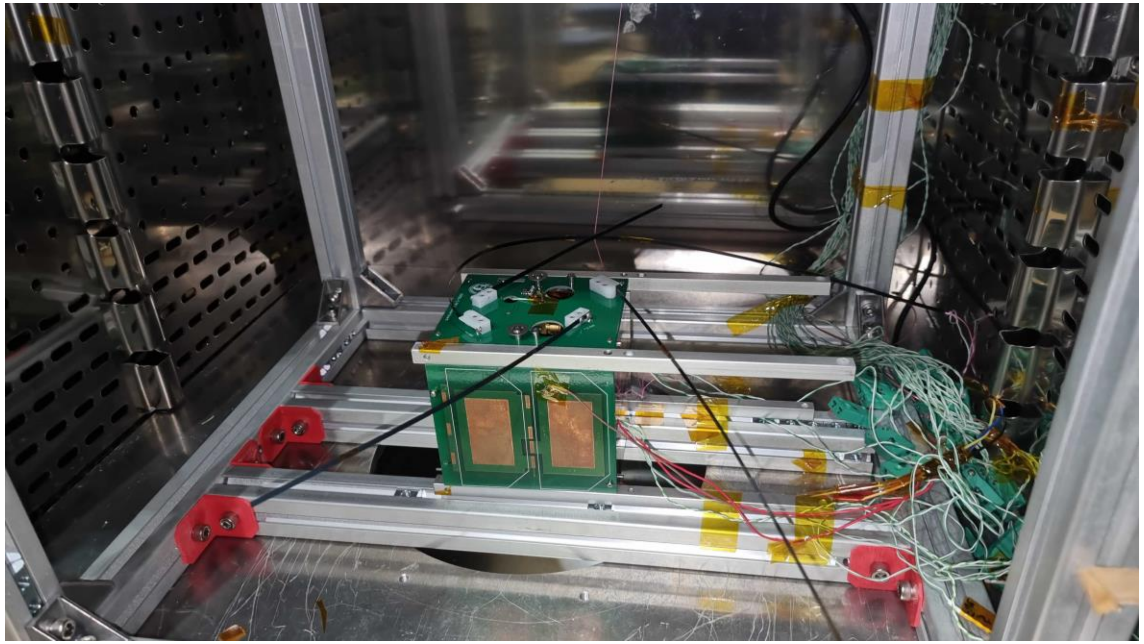


Communication link budget

3. Mission assurance

7.6 Testing phase (Deployment test)

- 25% of university satellites end up DoA (Dead on Arrival)
  - Antenna deployment failure?
- Make sure the antenna can be deployed in the worst case
  - Cold, low-battery, etc.



Antenna deployment test in low temperature

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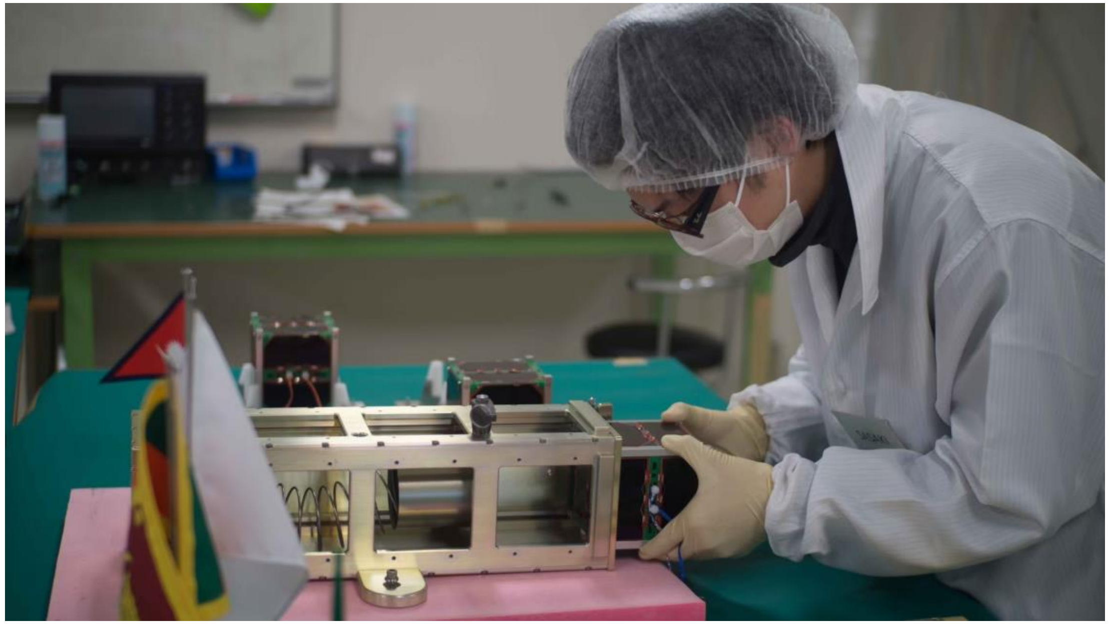
7.7 Testing phase (Fit check)

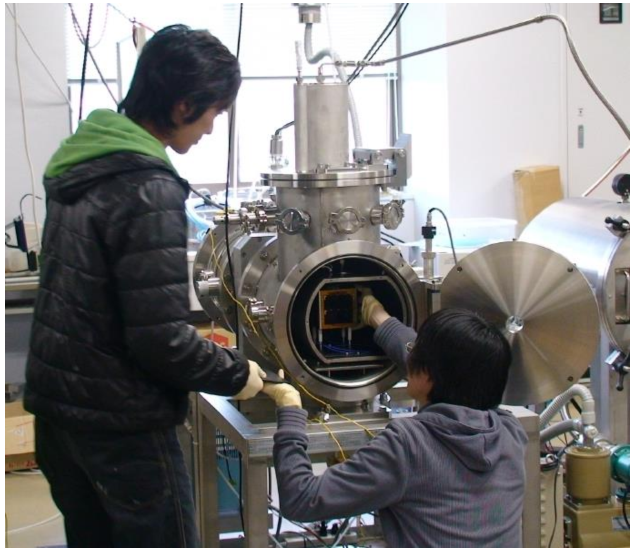
- CubeSats may not fit into a POD at satellite delivery
- The best and simplest way is to do a “fit-check” with an *official* POD borrowed from the launch provider
  - Both for the EM and the FM



Fit-check

3. Mission assurance

7.8 Testing phase (Thermal vacuum)



BIRDS satellite on-orbit data

- Thermal vacuum is thermal vacuum. Size doesn’t matter
- Temperature condition (high/low)
  - Use flight data of similar satellites flown in the same orbit
    - Many CubeSats have flown already in the ISS orbit
      - Use high beta angle data for high temperatures
  - More accurate than thermal analysis

7.12 Testing phase (Evaluation of test results)

- Check the consistency of the test results
- The pass/fail criteria should be established before the test
- If the results deviate from the tolerance limit, try to explain why
- If something hard to understand occurs randomly, record the observation
- Don’t be optimistic (fight against normalcy bias)
  - “Perhaps it won’t happen in orbit”
  - “It was just a random noise”
  - ”We just saw an illusion”
  - “Let’s forget about it”
- Confirm that the test equipment is used properly
  - Often wrong usage of RF equipment
  - Need to be checked by multiple people

“I didn’t see it”

From illust AC

3. Mission assurance

8.1 Operation phase (Preparation and Maintenance of Ground Systems)

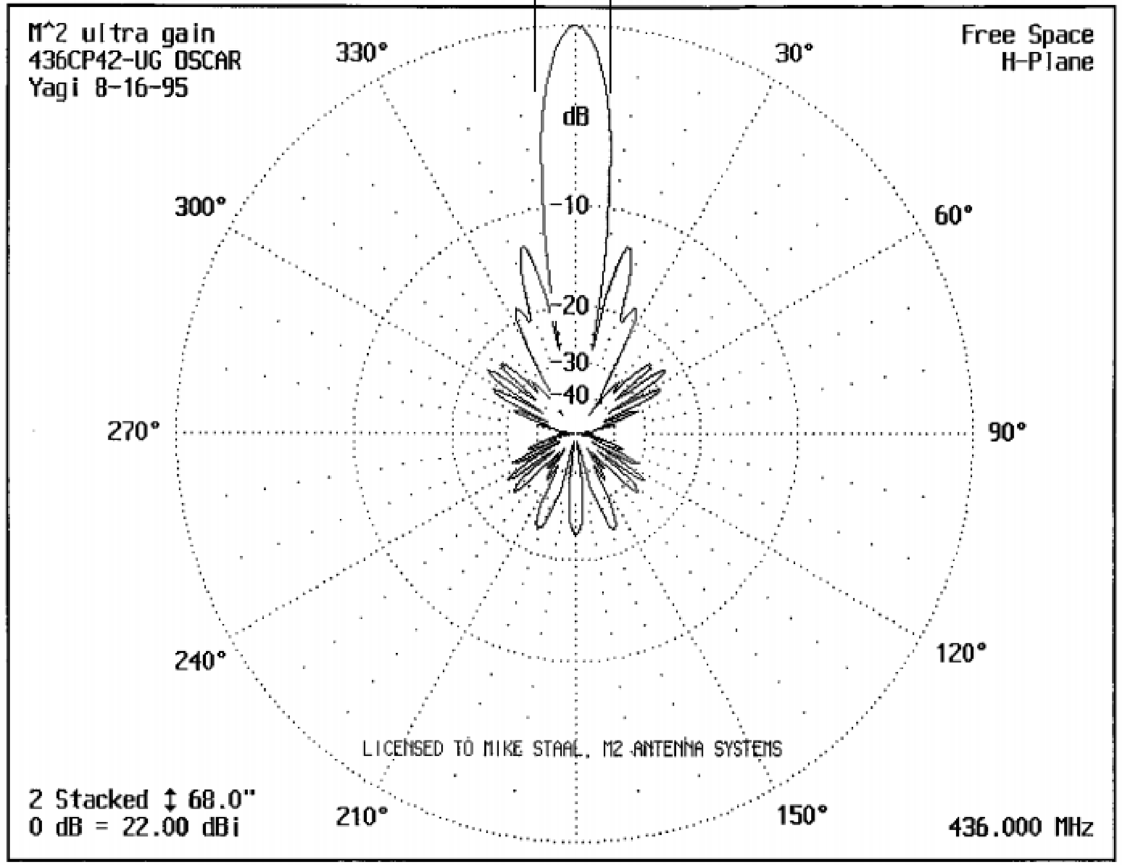
- Good location for a ground station
    1. No high buildings around the site
    2. No electromagnetic noise emission source nearby
    3. Short distance between the antenna and the radios
    4. Comfortable environment in the radio room which is **near to an office and 24-hours access**
    5. **Easy access to the antenna** for inspection and maintenance
- Periodic maintenance of antenna pointing
    - Track a known and reliable satellite
- Do not use a compass to find the north
    - The magnetic north ≠ Geographic north

Antenna is often broken

8.1 Operation phase (Preparation and Maintenance of Ground Systems)

Very narrow (~10deg)

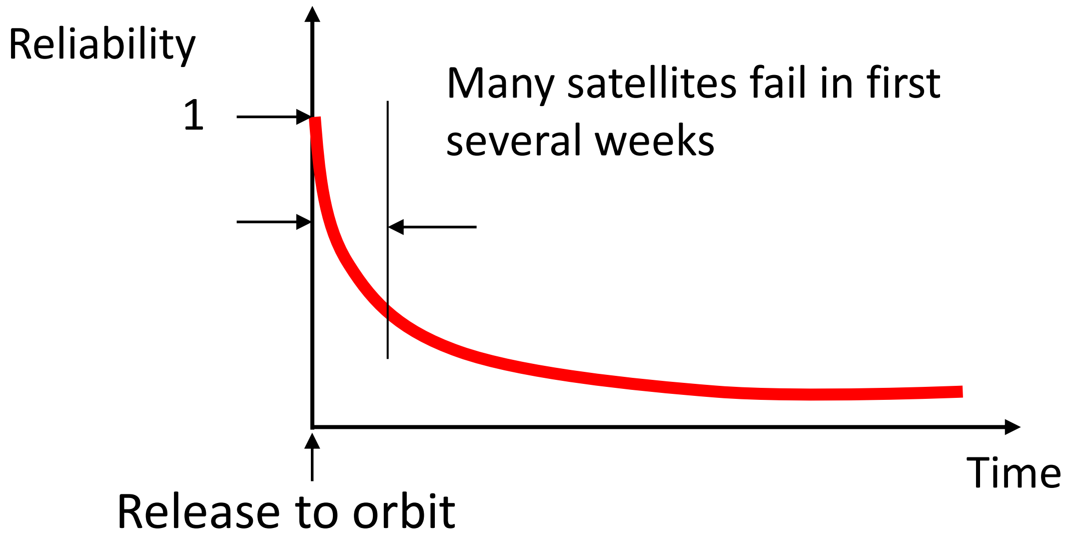
Misalignment of 10 deg matters seriously



Antenna pattern of UHF Yagi Antenna

8.2 Operation phase (Operation plan)

- Obtain the frequency license as soon as possible
  - In Japan, we get only a “preliminary license” before launch. Need a full license to operate the satellite officially and publish the results
- Do the main mission first. Achieve the minimum success criteria as soon as possible
  - Don’t be relaxed with the beacon signal



8.3 Operation phase (Handling Anomaly and Failures)

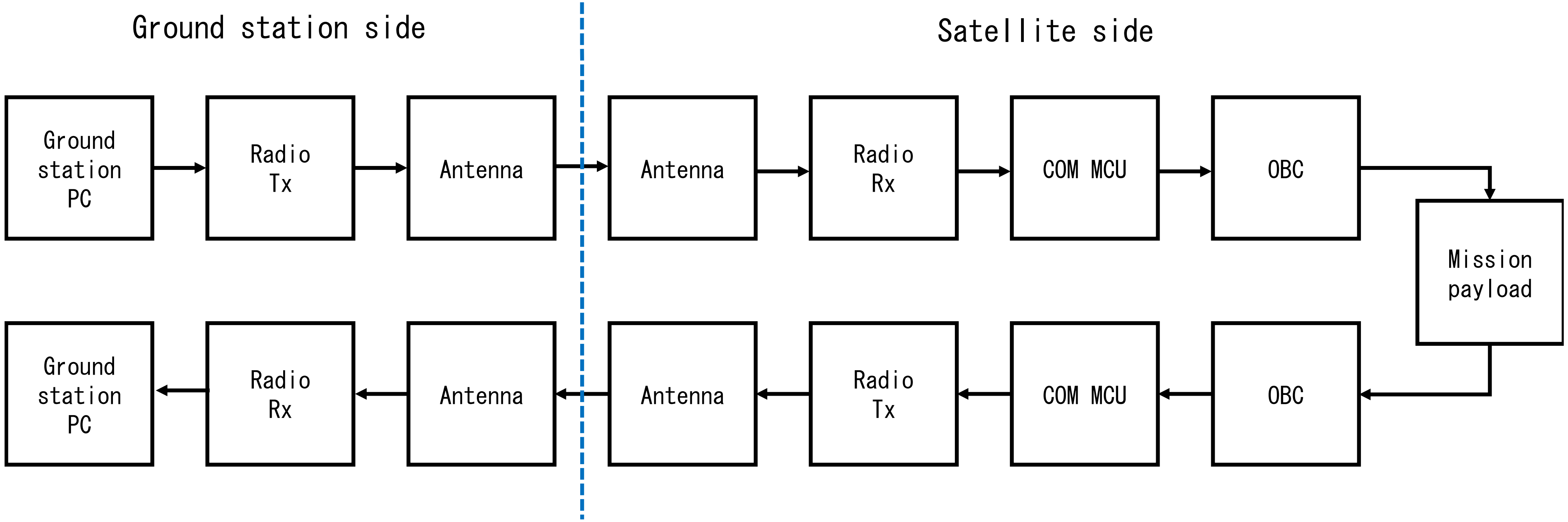
- Anomaly investigation
  - Never give up
  - P/I (faculty) should keep the motivation of the team

Keep motivation

いらすとや

8.3 Operation phase (Handling Anomaly and Failures)

- Do thorough FTAs for the next project
- Check along the information flow
- Flight spare on the ground is useful



Information flow diagram

9. After Satellite Operation

Lessons Learned

Documentation

Sharing know-how

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10.1 Sustainability of University Built Satellite Program (programmatic view)

- View as a program
  - Professor engaged as a program director
  - Academic career of junior researchers
- Funding
  - Efforts by individual professors
  - No miracle
    - Money won’t come from the heavens. Do something.

10.2 Sustainability of University Built Satellite Program (Strengthen the campus base)

- Support from the university management
  - Contribution to the university is necessary
    - Give something to university
    - Get something from university
  - The support may be limited if there is no value other than advertisement
  - Educational aspect
    - Engineering Design
    - Project Based Learning
    - Practical study of systems engineering
  - Continuous support may be obtained if the satellite program is a part of educational curriculum, though the amount is limited
- Collaboration among laboratories
  - From ***a project of Professor A*** to ***a program of Professors A, B, C***, and more.
  - Collaboration between engineering and science
  - Laboratory to make a satellite + Laboratory to use the satellite data (AI, IoT, etc.)

Devil's contract?

4. Conclusion

4. Conclusion

- University CubeSat projects can take a risk, but we still need mission success.
  - Not “failure is not an option”, but not “failure is accepted”.
- The second version of the “Mission Assurance Handbook for University-based Lean Satellites” is now available
  - Lean satellite: risk-taking, non-traditional approach toward low-cost and fast satellite building and operation
- Summary of points to be kept in mind by faculty members and students to improve the mission success rate
- Many of them apply to non-Japanese universities & new space companies
- The handbook is open to comments by the lean satellite community worldwide

Thank you very much.

[Disclaimer]
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