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
Lecturer Introduction

Shinichi Nakasuka, Ph.D.

Position:
1990 - Lecturer, Department of Aeronautics and Astronautics, University of Tokyo
1993 - Associate Professor, University of Tokyo
2004 - Professor, University of Tokyo
2012 - Member of Space Policy Committee, Cabinet Office (until 2022)
2013 - Chairperson, UNISEC-GLOBAL

Research Topics:
Micro/nano/pico-satellites, Novel Space Systems, Guidance, Navigation and Control
Autonomy and Intelligence for Space Systems
University of Tokyo’s CubeSat Project “XI”


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Survived for 20+ years in orbit!
- Image by CMOS Camera onboard XI-IV -
16-year trend in space about Battery

- Li-ion battery voltage history -

Various insights can be gained from satellites with long lifespans.

If your satellite survives in space for a long time, you can obtain various important information!

Larger Internal Impedance
Hodoyoshi-3,4 (Earth Observation Satellites Launched in 2014)

Low cost and affordable micro-satellites (50-60kg) to be developed within $3M and 2 years

Size: 50x50x80cm 60kg  Downlink: 10-20Mbps  Power: max 100W  average 50W

Attitude Control Capability:
- Stability 0.08 deg/s (Roll, Pitch)  0.8 deg/s (Yaw)
- Pointing accuracy 0.2 deg  2 deg
- Determination accuracy 0.0048 deg  0.048 deg
Wide Angle Camera
Chiba
(6m GSD Camera)
PROCYON (World first 50kg class deep space probe)

- The World First Interplanetary Micro-sat (65kg)
- Joint project with JAXA

Hayabusa-2
(~600kg)

LAICA
(Hydrogen imager)

PROCYON
(~65kg)

H-IIA Launch in Dec 2014

Quick (<14 months) development achieved

Earth’s hydrogen corona

Kameda et al., 2017 GRL

Hydrogen around 67P/Churyumov-Gerasimenko

©JAXA

©ESA
EQUULEUS Project: Space Exploration mission can be realized with just 10kg class satellites!

Size: 6U
Weight: 11kg

Solar Array Paddles with SADM (MMA) 50W@1AU
Chip-Scale Atomic Clock (CSAC) (JAXA)
Battery (U. of Tokyo)
PCU (U. of Tokyo)
CDH (U. of Tokyo)
Propellant (water) Tank

CubeSat Deep-space Transponder +SSPA (JAXA)
(64kbps@1.5M km with MGA)

X-Band LGA x5 (JAXA)
X-Band MGA (JAXA)

Water resistojet thrusters (DVx2, RCSx4) (U. of Tokyo)
(Isp >70s, Delta-V >70m/s)

PHOENIX (plasmasphere obs.) (U. of Tokyo)
DELPHINUS (lunar impact flashes obs.) (Nihon Univ.)

EQUULEUS Project: Space Exploration mission can be realized with just 10kg class satellites!

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(Isp >70s, Delta-V >70m/s)
Launched by Artemis-1 on Nov 16, 2022, flying towards EML2
“Store & Forward” collects ground information

Application areas: disaster prediction, water level monitoring, soil moisture, PH.....

Key Issue: **How to send data with very low RF power to the satellite?**

8mW low RF power, low data rate (300bps) transmission is tested in TRICOM-1R.

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Launch of TRICOM-1R by SS-520-5

- Launched on **Feb.2018** by the world smallest orbital rocket by JAXA/ISAS
- S&F and camera experiments successful
  - 8-130mW transmission from Japan, RWANDA Malaysia, Chille, etc. succeeded
- International Network of S&F is now being discussed
SONY “Sphere-1 Eye”

- Collaborative Project by SONY, JAXA, University of Tokyo
  - University of Tokyo developed 6U bus and conducted total system integration, and now is operation this satellite (good for stundet education !)
- **Mission:** SONY wants customers to operate satellite directly to capture various images (such as Earth, star, etc.)
- Developed within 2.5 years and **launched on January 3, 2023**
Captured Images by Sphere-1 Eye

Mexico

Bahama

Moon

Tanegashima

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Systems Engineering for Micro/nano/pico-satellites

1. Subsystems and their relationships
2. Possible causes of CubeSat failures
3. Why are space systems difficult?
4. Make your satellite “Die Hard”!
5. Start with a very simple satellite
6. Study and training before building a CubeSat
7. Define the target outcome of the project
8. Conclusions
1. Subsystems and their Relationships
Typical Satellite Subsystems

- **Thrustor**: Magnetic Torquer
  - RW
  - **Actuator**

- **Sensors, experimental system, camera, transponder, etc.**
  - **Mission Subsystem**

- **Computer**
  - OBC
  - **C&DH**
  - **Bus controller**
  - **Current status**
  - **Command**
  - **Data**

- **Receiver**
  - **Transmitter**
  - **Communication**
  - **AOCS** (Attitude and Orbit Control System)
  - Magnetic sensor, sun/star sensor, gyro, GPS

- **Command**
  - uplink
  - downlink

- **Data**
  - Sensor data
  - voltage, temperature

- **Power System**
  - **Solar Cell**
  - **Battery**
  - **Ground Station**

- **Thermal Control System**
  - MLI, cooler, heater, etc.

- **Structure and Mechanism System**
  - Antenna or paddle Motor

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Relationships between Subsystems

You should design subsystem interfaces properly.

- How many and what kind of CPUs are to be used?
  - One or two OBCs for main functions and attitude control, or more?
- Between C&DH and other subsystems
  - Information line: RS-232C, RS-422, MIL-STD-1553B, SpaceWire, CAN bus, ----
  - Interval of data exchange and amount of data to be transferred
  - What kind of data to be transferred (house keeping / mission data)
- Between C&DH and communication subsystem
  - How will large volumes of data for downlink be stored?
- Between C&DH and mission subsystem
  - How will mission components be controlled and how are those data received?
- Between power subsystem and other subsystems
  - What kind of reset (power off-on) function is to be implemented?

Top level design will decide satellite architecture
2. Possible Causes of CubeSat Failures
Past Failures of CubeSat

**Failure rate is still about 50%**

CubeSat Mission Status, 2000-present (271 spacecraft)

- **Successful mission** is only 35%
- **Did not function after release from rocket**
- **Died soon after operation started**
- **Did not function after release from rocket**
- **Unknown** is 14.8%
- **Launch** fail is 6.3%
- **DOA (Dead on Arrival)** is 32.5%

Based on Study by St. Louis Univ.  
https://sites.google.com/a/slu.edu/swartwout/cubesat-database

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Frequent Causes of Failure and Countermeasures

What should you take special care of?

● Radiation causes electronics failures
  ✓ Use space-proven parts or conduct radiation tests during early development phases

● Electric power subsystem fails to provide power, or battery voltage gets very low and cannot be recovered
  ✓ Design satellite behaviors under low battery voltage
  ✓ Make solar power generation possible in any situation

● Communication subsystem fails to communicate with the ground station because of component failures, insufficient RF power or EMI (Electromagnetic Interference)...
  ✓ Implement backup systems (redundant receivers, etc.)
  ✓ Calculate the link equation correctly and add enough link margin
  ✓ Conduct ground tests using EM or FM in a realistic situation
  ✓ Find and consult with communication technology experts

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3. Why Space Systems are Difficult?
Why space system is difficult?

- Harsh Space Environment -

- Vacuum
  - Vaporization, cold welding, friction, electric discharge, change of material, heat spot....

- Radiation
  - Electronics parts malfunction and breakdown, degradation of solar cells and materials....

- Thermal
  - Large temperature differences/cycles, heat shock, heat spot....

- Launch
  - Vibration, shock, acceleration, sound vibration....

- Distance
  - Long range communication over 500-2000 km....

Others: Atomic Oxygen, Plasma, Debris/Meteoroids, Ultraviolet rays
“Non-maintainable System”

Once launched, you cannot touch your satellite. Then what should you do?

- A satellite cannot be touched until the end of its life once it is launched. called “non-maintainable system”

- Sometimes a satellite has to survive in space for more than 10 years without any human interactions. Therefore……

- Imagine all the possible events and anomalies which may happen to your satellite and prepare countermeasures for them. Imagination is very important!

- Conduct ground tests in various settings to ensure proper functioning of your satellite in the space environment, in various operation modes.
4. Make Your Satellite “Die Hard”!
"Water flow" project management and lots of ground tests

Mission Creation

Breadboard Model (BBM) Phase

Engineering Model (EM) Phase

Flight Model (FM) Phase

Launch & Operation

System concept design

Trial-and-error of detailed design

Radiation tests
Simple function tests on TableSat

Assuring functions in space environment

Space environment tests (vibration, shock, thermal, thermal vacuum tests) with strong load (Qualification Test)

Fabrication as designed

Space environment tests (vibration, shock, thermal, thermal vacuum tests) with launch load (Acceptance Test)

Review
Ground Tests

PDR

CDR

LRR

Return to the previous stage should be avoided as much as possible
“Table-sat Test” checks proper functionalities and connections between components.
Satellite Integration

Inside View of Clean Room at Waseda University

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Space Environment Tests

Vacuum Chamber at KIT

Vibration Test Facility at KIT

H4 (Ready for testing)

H3 (Ready for testing)

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How to realize a certain level of reliability with limited resources (size, weight, power)??

“Die Hard” system is essential!!
- Mutual monitoring or hierarchical monitoring
- “Reset (power off-on)” operation
- Monitoring excess current against radiation effects
Combination of “High performance but not space-proven” processor and “Low performance but space-proven” processor

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Example of Useful “Reset” Mechanism

Usage of Counter Circuit

One thoughtful idea to use a “counter circuit” for a reset mechanism

Command from the ground

When the counter becomes full, it resets RX and OBC

“Counter reset” is possible by a command from the ground, which is possible only when RX and OBC are functioning correctly

Various Components
Fundamental Modes and Sequence (One Typical Example)

(1) Initial mode
- Unpredicted tumbling
- CPU and TX on

(2) Safe mode
- Minimum components-on
- Get some sun light

(3) Sun acquisition mode
- Attitude to get large solar power generation
- Components checking
- Required components-on, preferably one-by-one

(4) Mission stand-by mode
- Attitude easy to move to mission mode
- Power balance is + (plus)
- Almost all components-on

(5) Mission mode
- Full components-on
- Attitude control required by mission

Release from Rocket
Release switch automatically turns on satellite system

By uplink command
- Battery V > XX (v)
- Compo. used in (3) are good

By uplink command
- Battery V > YY (v)
- Compo. used in (4) are good

By uplink command
- Battery V > ZZ (v)
- Mission is required

Automatic transition when anomaly occurs or battery voltage < XX volt

By uplink command
Or automatically

These modes are optional to keep solar power generation higher than consumption

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Transfer to Safe Mode

*Prepare safe mode to enhance survivability*

- Sometimes anomalous situation affect satellites such that:
  - the battery voltage drops very low
  - the downlinked telemetry include such data that cannot be explained
  - the satellite attitude motion is strange, etc.
- The maximum survivability can be obtained by making your satellite transfer to “safe mode” which assures:
  - minimum power consumption of components
  - power generation is larger than power consumption
  - sufficient data for analysis of the cause of anomaly is downlinked
- Safe mode should be designed such that it can be entered even when the ground station cannot communicate with your satellite.

*Safe mode is “Survival Mode”*
Use Reliable Communication System

You should somehow communicate with the satellite.

- “Center line” is very important!
  - Assure proper functioning of the Ground station ⇒ Receiver ⇒ OBC route
  - Should use reliable CPU inside the communication receiver
  - It is recommended that command from the ground can reset components without using the OBC

- Design an effective antennae
  - Antenna should be stowed during launch, and take a proper shape after deployment

- Even if any components fail, some information should be downlinked to ground
  - For example, CW beacon can be used as a backup for telemetry downlink

- Functional redundancy
  - If you use S-band for house keeping and X-band for mission data, in case of S-band failure, X-band can also be used for downlink of house keeping telemetry
Combination of “High performance but not space-proven” processor and “Low performance but space-proven” processor.
Enabling Solar Power Generation in Any Attitude

Solar paddle type vs. Body mount type

- Very large power generation
- Limited power generation

- Power generation is possible only when attitude control works properly
- Power generation is possible regardless of attitude

For a 1U CubeSat, body mounted cells on all the 6 surfaces are recommended.

Hodoyoshi-4 (2014)

TRICOM-1R (2018)
5. Start with a very simple satellite
“Simple” is Best

- In your 1\textsuperscript{st} project, start with a simple and easy-to-realize type of mission, and if you still have additional time/budget, then try to consider additional missions
  - start from “KISS” = Keep It “Stupidly Simple”
- “Functioning CubeSat in space” in itself is an important mission.
  - Pursue survivability as much as possible
- Find out and pursue \textit{what you can do with your limited resources}, not aiming at too high a level (“high level” should be pursued after your first success !)
- Try to find external supporters
  - Technical consultation, testing facility, donation, etc.
  - Promotion of your activities to the general public is important
6. Study and training before building a CubeSat
Study and Training before CubeSat

What should you learn before developing a CubeSat?

- Basic knowledge on mathematics, physics, rigid body dynamics, electronics, radio frequency…..
- Printed circuit board (PCB) design to realize certain functions
- Orbital mechanics, attitude dynamics/control and thermal/structure dynamics for space systems
- Practical training using “real” projects

“CanSat” is an excellent tool

- Project management and teamwork
- System level design (weight/power budgeting, etc.)
- How to make a “die hard” system
- Ground tests and operations from the ground

Once you pass you CanSat to rocket engineers, you cannot contact it any more!
Initial Training for satellite development CanSats 1999 - now
Hands-on Training Tool: CanSat

Many universities in Japan have been trained by CanSat.

ARLISS: A Rocket Launch for International Student Satellites in Nevada, USA

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AEROPAC (Amateur Rocket Group) lifts CanSat to 3.6 km altitude in Nevada, and during descent (about 15 minutes), various experiments are conducted.
How to lift a CanSat?

Simplest way: drop from a high building

Drone or UAV have also been used recently

Amateur Rocket Launch and Descent by Parachute

Helium Balloon

CANSAT Gondola

Tether

CANSAT Drop (20 sec)

3.6km altitude

ARLISS in USA

carrier

launch

Release from rocket

nosecone

15-20 min after release

100-200m

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Example Mission “Comeback Competition”

*CanSat International Competition in ARLISS*

- Mission: to autonomously come back to the target after release from a rocket
- Flyback-type (parafoil, fixed wing, drone) vs rover-type
“Problem Solving” training is important!

- Life is full of “problem solving”
  - For most of the problems, there are not answers yet.
  - Most of them cannot be solved by knowledge and skills in a single area
  - Setting “goal” by yourself is also important

- Satellite/CanSat development provides excellent opportunity of training for “problem solving”
  - No correct answers exist before
  - Cannot be developed only by single technological area
  - You can set your own goals for your project

- You can get good training only when you have strong desire to solve the problem!!
  - Satellite/CanSat development provides this motivation
2017, our team reached 1.34m to the target by GPS navigation, and changed to “camera navigation” to reach the target. But…

Because of coming sun-light, its camera could not recognize the target and gave up after some waiting time.
They still had one more chance on two days after…

- They modified the strategy and changed the software.
- They did on-site tests many times to check the new software.
- And realize “0 m” to the target in their second run !

This is really a “problem solving” !!

Strong motivation “We want to win the competition!”
Failure is also an Education

Parachute and main body were separated and the main body crashed on the ground (2000)

- Students can learn many things from failures
- Engineers should experience failures while the project size is small
CLTP (CanSat education) History & Participants

CLTP1 (Wakayama Univ. in Feb-March, 2011)
12 participants from 10 countries, Algeria, Australia, Egypt, Guatemala, Mexico, Nigeria, Peru, Sri Lanka, Turkey (3), Vietnam.

CLTP2 (Nihon Univ. in Nov-Dec, 2011)
10 participants from 10 countries, Indonesia, Malaysia, Nigeria, Vietnam, Ghana, Peru, Singapore, Mongolia, Thailand, Turkey.

CLTP3 (Tokyo Metropolitan Univ. in July-August, 2012)
10 participants from 9 countries, Egypt (2), Nigeria, Namibia, Turkey, Lithuania, Mongolia, Israel, Philippines, Brazil.

<2013~ iCanSat Kit: CLTP4-7>

CLTP4 (Keio Univ. in July-August, 2013)
9 participants from 6 countries, Mexico(4), Angola, Mongolia, The Philippines, Bangladesh, Japan.

CLTP5 (Hokkaido Univ. in Sept, 2014)
7 participants from 5 countries, Korea (2), Peru, Mongolia, Mexico (2), Egypt.

CLTP6 (Hokkaido Univ. in August, 2015)
8 participants from 8 countries, namely Angola, UN(Austria), New Zealand, Tunisia, Turkey, Egypt, Bangladesh, Mexico

CLTP7 (Hokkaido Univ. in Sep, 2016)
8 from 7 countries, namely Egypt, Myanmar, Peru, Nepal (2), Mongolia, Serbia, Dominican Republic

<2017~ HEPTA-Sat Kit: CLTP8-10>

CLTP8 (Nihon Univ. in Sep, 2017)
9 from 7 countries, namely Bolivia, Egypt, El Salvador, Malaysia, Nepal, Turkey

CLTP9 (Nihon Univ. in Aug, 2018)
8 from 6 countries, namely Argentina, India, Japan, Malaysia, Mongolia, UAE

CLTP10 (Nihon Univ. in Aug, 2019)
15 from 11 countries, namely Australia, Bhutan, Bulgaria, Cambodia, Colombia, Kenya, Morocco, Myanmar, Peru, Rwanda, Zimbabwe
7. Define the Target Outcome of the Project
Various Options for Satellite Development

You can buy CubeSat components from websites easily. How to mix purchased components and ones of your own design?

1) **Assemble purchased components with a fixed mission (i.e., “kit”), do ground tests, and launch/operation**
   - **Option 1-1** Add one original mission with your own designed component

2) **Create your own mission, buy components to realize it, do ground tests, and launch/operation**
   - **Option 2-1** Design/fabricate a few components
   - **Option 2-2** Design/fabricate all the components

What we did for our first CubeSat

Find an adequate option considering your team’s expertise and your target outcomes.
### Expertise to be Obtained by Project

**What can you learn in each option?**

<table>
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<tr>
<th>Options</th>
<th>Mission creation</th>
<th>Architecture design</th>
<th>System Analysis</th>
<th>Sub system design</th>
<th>Project management</th>
<th>AI&amp;T</th>
<th>Ground operation</th>
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- **1-1)**: Purchased Kit + design/fabrication of one original mission by yourself
- **2-1)**: Original mission with purchased components + some designed components

**Note:**

- **AI&T**: Assembly, Integration and Test
- "s": small effect
- "L": large effect

**Two recommended options**

- Easier:
  - 1-1)
- More difficult:
  - 2-1)
Various Skills to be Obtained

CubeSat or satellite projects will give you……

- **Practical Training of Whole Cycle of a Space Project**
  - Mission conceptualization, satellite design, fabrication, ground test, modification, launch and operation
  - Know what is important and what is not.

- **Important Experience of Engineering**
  - “Synthesis” (not analysis) to realize your mission
  - Feedback from the real world to evaluate design, test, etc.
  - Learning from failures (while the project cost is small)

- **Education in Project Management**
  - Four Managements: “*Time, human resource, cost and risk*”
  - Team work, conflict resolution, discussion, documentation
  - International cooperation, negotiation, mutual understanding

- **Also contributes to other technological areas!**
8. Conclusions
Keep these in mind!

- Survivability in space is the most important. Imagine as many possible failures as you can and prepare countermeasures against them.

- “Reset” is an effective way to recover your satellite from anomalies. Please prepare effective ways to do a “reset”.

- Start with a very simple CubeSat. After your first success, you can step up to more sophisticated satellites.

- Study various knowledge, skills, and project management before developing a satellite. CanSat type of hands-on training is very effective!

- Define the target outcome of your project. Only the launch and operation of your first satellite is not enough. You can get something and continue it to your next project.

- Have fun! This spirit will provide you with energy, endurance, and a never-give-up mindset!
Thank you very much.

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